The design and formative evaluation of computer based qualitative modelling environments for schools

Thesis

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The design and formative evaluation of computer based qualitative modelling environments for schools

Children building models

Mary E. Webb BSc, MSc

Institute of Educational Technology
The Open University
Milton Keynes
UK

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Abstract

This research investigated how computers might enable young learners to build models so that they can express and explore their ideas and hence they can gain understanding of the subject matter as well as developing modelling abilities.

A design for a qualitative modelling environment was produced, which incorporated a simple rule-based metaphor that could be presented as a diagram. The design was founded on empirical evidence of children modelling as well as theoretical grounds. This research originated in and contributed to the Modus Project, a joint venture between King's College London and the Advisory Unit for Microtechnology in Education, Hertfordshire County Council. A prototype of the software, Expert Builder, was implemented by software engineers from the Modus team. The initial stage of evaluation, based on a questionnaire survey and widespread trialling, established that the tool could be used in a wide range of educational contexts.

A detailed study of children using the qualitative modelling environment was conducted in three primary schools involving 34 pupils, aged nine to 11. They used the modelling environment within the classroom in their normal curriculum work over one school year on a variety of topics assisted by their class teacher. The modelling environment enabled cooperative groupwork and supported pupils in consolidating and extending their knowledge. A formative evaluation was used to inform the design of a revised version of the software. In addition the experiences of children using the software were analysed.

A framework was developed which characterised the stages in the modelling process. Teachers in the study were observed to demonstrate the earlier stages of the modelling process and then to set tasks for the children based on the later stages of building and testing the models. The evidence suggested that the abilities to model were context dependent so that pupils as young as nine years old could undertake the whole modelling process provided that they were working on subject matter with which they were familiar. The teachers made use of computer based modelling in order to develop

and reinforce pupils' understanding of various aspects of the curriculum and therefore they chose modelling tasks for the children. However in one school the children were given the opportunity to design and build models of their own choice and they demonstrated that they were able to carry out all the stages in the modelling process.

A taxonomy of computer based modelling is proposed which could be used to inform decisions about the design of the modelling curriculum and could provide a basis for researchers investigating the modelling process. This would be useful for further research into the intellectual and social activities of people learning to model and for teachers seeking to develop a framework for the modelling curriculum. The National Curriculum (Department of Education and Science and the Welsh Office, 1990) specifies that early steps in computer based modelling should involve exploring models developed by others and pupils are not required to build models themselves until level 7 which is expected to be reached by more able 14 year-olds. In this thesis it is argued that a modelling curriculum should provide early opportunities for pupils to undertake the modelling process by developing simple models on familiar subject matter as well as opportunities for exploring more complex models as evidence from research reported in this thesis suggests that younger pupils are able to build models.

In this way pupils will be enabled to acquire modelling capability as well as developing their understanding of a range of topics through modelling. Progression in modelling capability would involve constructing models of more complex situations and using a wider range of modelling environments.

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Chapter 1 Introduction

The goal of this research was to find ways of using computers to enable learners to express and explore their ideas and understanding as qualitative models that they could run and evaluate. This would provide opportunities for a new type of learning activity that would help learners in two main ways. First, it would support learners in developing knowledge and understanding of the topic that they were working on. It was possible that this method of working would be more beneficial to learning than other methods. Secondly it would develop learners' modelling skills and abilities, a desirable goal in view of the increasing use of modelling as a tool in business, industry and research. An important research question was to what extent are children able to develop qualitative computer based models in different curriculum areas? It will be argued that the research has implications for the school curriculum because the provision of more user-friendly modelling tools enables a wider range of learners to undertake computer based modelling activities that were previously regarded as too advanced.

1.1 Structure of the thesis

The thesis consists of ten chapters and some appendices. In this chapter the main research questions and the research approach are introduced. Chapter 2 reviews computer based modelling and discusses the systems that were available to inform the design of the modelling environment. Chapter 3 explores the relationship between learning and modelling by reviewing relevant learning theory and empirical work. Chapter 4 reviews the possible modelling metaphors and justifies the choice of a rule based metaphor. Chapter 5 discusses design issues and outlines the choices made and the reasons for those decisions. Chapter 6 describes the initial evaluation study including the questionnaire survey and a pilot study of classroom use. Chapter 7 describes the methods and rationale for the detailed classroom study and Chapter 8 presents the results. Chapter 9 presents the analysis of the modelling process and discusses the curriculum for modelling. Chapter 10 discusses the conclusions and comments on other developments that have taken place since the modelling environment was designed. Implications for further work are also discussed in Chapter 10.

1.2 Background

This research was carried out in association with the Modus Project, a collaboration between the Advisory Unit for Microtechnology in Education, Hatfield and the Educational Computing Unit at King's College London (formerly incorporating Chelsea Computers in the Curriculum Project). The aims of the Modus Project were to investigate the opportunities and benefits of computer based modelling in schools and to develop software for computer based modelling. Both the Advisory Unit and King's College had extensive experience of researching information technology in the classroom and designing educational software. The Advisory Unit was a pioneer in the introduction of computers in schools encouraging schools to work with generic software such as databases and spreadsheets and particularly LOGO (e.g. Blythe and Noss 1983). The philosophy of the Advisory Unit was to promote child-centred learning and group work with computers and to "put the power of the computer into the hands of the learner". King's College had already developed DMS, the Dynamic Modelling System, which school children were using, particularly in A level physics, to construct models of dynamic systems (Wong 1987). The philosophy of the Modus Project was to harness the increasing power of computers in order to provide better and more user-friendly facilities for computer based modelling that would enable such modelling to be accessible to a wider range of learners in many curriculum areas. It was intended that the software should be suitable for use across the curriculum and be usable by a wide age range of learners including pupils in primary and secondary schools.

During the first stage of the Modus Project a feasibility study was conducted, which identified a need for particular computer based modelling facilities and support. This study considered the software currently available to schools and researched teachers' ideas and perceptions of modelling (Webb and Hassell 1988). The main conclusion of this study was that a range of computer based modelling facilities was needed that would enable children to build a variety of different types of models on topics from many curriculum areas. Following the feasibility study the Modus Project team decided to work towards the development of an integrated modelling system. This would enable learners from primary school pupils through to students in higher education to build models on most topics (Hassell and Webb 1990). The system was intended to be used within various curriculum areas such as science, geography and history. The rationale for encouraging the use of modelling in schools was based on two main principles:

- Modelling is an important process in business, industry and research. Therefore learners should develop an understanding of the advantages and limitations of modelling as well as acquiring modelling skills.
- While modelling, pupils are actively engaged in selecting, organising and re-synthesising knowledge. This may assist them in developing understanding of the subject matter of the model.

The system was expected to contain facilities for dynamic and quantitative modelling, probabilistic modelling, qualitative modelling and spatial modelling. With such a system it was to be possible for users to select the tools that they needed and integrate a variety of modelling techniques in order to create a model. This ambitious goal was tackled by researching possible implementation methods and developing parts of the system as prototypes that could be trialled and improved. Finally these methods would be integrated into the Modus environment which would contain a general modelling language. My part of the project was to investigate the provision of the qualitative modelling facility and to design and evaluate this facility.

1.3 The approach

The idea for a qualitative modelling environment had been born out of a classroom need perceived by teachers and those who support them (Webb and Hassell 1988). The need was identified for a modelling environment that would enable users to express relationships in non-quantitative ways. The requirement by most modelling environments for all relationships to be expressed in precise mathematical terms and for all values to be defined numerically was felt, by teachers, to be a barrier to modelling for many younger learners. In addition, a range of problem solving and decision-making processes that did not lend themselves to precise mathematical formulation had been identified by teachers. Teachers and pupils might want to use some mathematical expressions such as *more than* or *less than* within their models but they would not want to specify numbers or amounts for each variable. The use of the qualitative modelling environment in this project therefore denotes an emphasis on non-numeric values and relationships but with the possibility of some mathematical expressions such as *more than* or *less than* being used. This definition of *qualitative* encompasses the semi-quantitative approach of Bliss et al. (1993) in which semi-quantitative models were described as a sub-category of qualitative models.

It was necessary to identify a suitable metaphor for the modelling environment that would enable young learners, with little or no computing experience, to express and evaluate their ideas and understanding. In particular the metaphor needed to enable the construction of decision making and problem solving models and models that explore cause and effect.

The term "metaphor" is used to denote the representational structures together with the functional mechanisms that would form the basis of the modelling environment. It was assumed that this would be a single coherent manifestation which might derive from the real world or from a computational source. The structure and function of the metaphor would need to have many points of correspondence to the structure of the modellers ideas and knowledge and to the processes employed to use this knowledge to solve problems and make decisions. The environment would need to make the metaphor comprehensible and be easy to manipulate. The design also had to take into account how children's learning, in a range of curriculum areas, could be enhanced by undertaking modelling activities. It was therefore important to determine where relevant learning theory might have implications for the design. The software needed to be incorporated into the classroom setting so empirical evidence of children undertaking modelling activities and other related work was also explored.

The modelling environment was implemented by software engineers in the Modus team. It was then evaluated by a questionnaire survey and detailed classroom studies. The questionnaire survey involved users and potential users of the software in 140 educational institutions, ranging from primary schools to higher education, who had volunteered to trial the software. The classroom studies were conducted in three primary schools and involved 51 pupils in total. This evaluation was classroom based since the aim was to develop this software into a system that could be used in the classroom.

1.3.1 Identifying computer based modelling in education

A first step was to establish some clear definitions that could be used as a basis for identifying relevant data from empirical studies. The term "model" is used in many contexts and with a variety of meanings. Some writers, for example, considered a piece of prose, which described a system or concept, to be a "word model". If this extremely broad definition of modelling were extended to computer based modelling, more or less anything created on a computer would be a model, including, for example, a word processed description of a system. Although it is obviously possible to produce a *description* of any model in prose, in order to enable processing by a computer so that the model can be run, the model needs to be represented using symbols that can provide a more precise meaning than is possible with prose. The Modus Project decided to define a model as: a formal representation of a problem, process, idea or system. This was an extension of that given by Jeffers (1978) who defined a model as "a formal expression of a problem in either physical or mathematical terms". A model is never an exact replica but represents one or more aspects of the structure, properties or behaviour of what is being modelled. A model may take many forms, including a diagram, a mathematical formula, a physical construction, or a set of logical statements. In the context of computer based modelling, an essential feature of a model was considered to be a structure which gives a formal and precise description. A further important characteristic of a computer model is that it should be executable, i.e. it should be possible to input values and run the model to obtain output.

Which, if any, of the computer based activities that have taken place in schools could be regarded as modelling? Modelling was defined, by the Modus project team, as a process in which a model of a situation is constructed for a particular purpose and it is then tested and evaluated by comparing its outputs with data from the real world. The process may involve iteration of some steps until the model is adequate for its purpose. Much use has been made of computer simulations in schools, including simulations of industrial processes, experiments and natural systems. Such simulation programs were based on models but the models were generally inaccessible to the user as they were buried in the program code. The user was not usually able to view the model or change it. The typical activity was for the user to alter the values of the variables in the model and to observe the effects on model output. The user was often encouraged to make deductions about the real world assuming that it behaved in a similar way to the model rather than comparing the model's outputs with events in the real world. This use of such simulation packages contains few of the important elements of modelling.

Computer programming was another candidate for consideration as a modelling activity. A computer program may represent a problem or process in the real world or it may be an implementation of a solution to a problem. A number of computer programs are models of computer processes rather than processes that take place in the rest of the world. It can therefore be argued that all computer programs are models but for learners the modelling of events that take place outside the world of the computer are generally more valuable. The turtle graphics of LOGO, for example, provides a simple modelling environment which does enable the modelling of processes that take place in the world outside the computer.

1.3.2 The contribution of modelling to learning

An important question, for this research, was how could children's learning be enhanced by modelling and in what ways could software design provide increased opportunities for this effect? The suggestion that learning could be enhanced by modelling came principally from work with LOGO (Papert 1980). Papert's work was based on the Piagetian notion of learners being active builders of their own intellectual structures. This idea was also central to the constructivist approach associated with Kelly (1971) and promoted by Driver and Easley (1978). The theoretical basis of this approach is explored in Chapter 3 where it is argued that the modelling environment should be designed to help learners to express their knowledge by making the transformation of that knowledge from their own mental representations or "mental models" to those of the modelling environment, as easy as possible. The term "mental model" is discussed in Chapter 3 (Section 3.4) where it is suggested that this type of representation is particularly important in learning. It is also argued that people may use other mental representations in addition to mental models. The term "mental representation" is used to refer to a whole range of mental mechanisms including mental models.

There was some support for the view that mathematical understanding could be developed through programming in LOGO (e.g. Blythe and Noss, 1983, Harel and Papert, 1990) and so it is argued that, given appropriate tools with which children can express and evaluate their ideas, it may be possible to enhance understanding in other domains. There has been continuing debate and conflicting evidence about the possible cognitive benefits of learning to program in LOGO (Pea and Kurland, 1986). The debate is outlined in this thesis but cannot be resolved. It is important because it is possible that computer based qualitative modelling could contribute to the development of general thinking skills. Therefore this possibility needed to be considered in relation to the design of the qualitative modelling environment. In particular, qualitative modelling usually involves some form of reasoning so there may be opportunities to develop children's reasoning ability through modelling. The literature has also been examined in order to determine theories about how people reason and it is argued that the modelling environment should support everyday reasoning rather than formal logic.

LOGO has been in widespread use in schools for a number of years but there is still no generally accepted view of how it can contribute to children's learning except perhaps in understanding aspects of mathematics. Computer based qualitative modelling was expected to be used in a wide range of subject areas and was intended, as indeed was LOGO, in Papert's view, to be a part of a whole learning environment. The evaluation therefore adopted a broad classroom-based approach in which the qualitative modelling environment was provided to teachers to use in ways which they felt to be appropriate. In this way it was possible to evaluate the software as a tool for practical classroom applications. The range of learning activities that were developed were then analysed in order to characterise learning opportunities and to identify the types of skills and processes that were required to use the environment.

1.3.3 The modelling metaphor

At the start of this research there was no computer based qualitative modelling environment in general use in schools. The options were either to identify a suitable metaphor from amongst the tools in use in business, industry and research or to develop a completely new idea. The first option led to the identification of a suitable metaphor. The aim was to identify a modelling metaphor that was sufficiently powerful to provide for a wide range of qualitative modelling at various levels but was easy enough for inexperienced and younger pupils to begin to use and build a model in a short time. One clear constraint was that the software would be developed into a finished product that could be used on the computers generally available in schools in about three years from the start of this project, so algorithms that required the power of advanced workstations would not be suitable. There were a number of qualitative modelling tools in use in business and industry but they were designed to be used by adults with considerable computing expertise and were therefore too complicated for use by school children.

Identifying a metaphor involved a review of existing modelling metaphors and software environments, examining evidence of their use, observing them in use, and considering how they might be adapted for use by school children. The identification of a suitable modelling metaphor had to be considered alongside the design of the user interface because it became clear that an important principle to apply to the design was that of "naive realism", coined by DiSessa and Abelson (1986), an extension of the "what you see is what you have" idea. This approach has become common-place with text editors and graphics programs but, prior to the design of Boxer by DiSessa (1986), it had not been applied to the design of programming languages. The principle is that users should be able to pretend that what they see on the screen is their computational world in its entirety. For example, any text that appears on the screen, whether produced by the system, entered by the user, or constructed by a program would be able to be moved, copied, changed or, if it is program text, evaluated. Similarly the value of a variable would be able to be changed simply by altering the contents of the variable box on the screen. In relation to the modelling metaphor this meant that it must be fully representable in a graphical or pictorial view on the screen. Users would be able to interact with this view so that, for example, any changes that they made to their model would be made directly on the model on the screen. The model would also be run through the same screen view. The search for a suitable modelling metaphor is described in Chapter 4. It is argued that a rule-based metaphor, similar to that of some commercial expert system shells used in business, was the most appropriate metaphor available and that a graphical user interface would facilitate constructing the model and make the inference mechanism easy to understand.

1.3.4 Design of the modelling environment

As stated earlier, the identification of the modelling metaphor and the design were tackled at the same time but once the basic design and metaphor had been determined there were still a number of details that had to be researched. The design had to take into account the possible classroom setting including support for children working in small groups, the need for pupils to be able to start making use of the software fairly quickly and to have access to powerful facilities as they progressed as well as practical considerations about the technical feasibility and the resources available for implementation. This part of the work involved exploring techniques used in other environments and examining evidence of how learnable they were, prototyping ideas for the user interface design and discussing technical feasibility with the Modus team and others. The design was based on the principle of naive realism but most of the design details were decided from observations of software in use rather than being based on a detailed set of design guidelines. Design issues are discussed in Chapter 5. The design was implemented, by the Modus software engineers and the resulting prototype was named, Expert Builder.

1.3.5 The range of applications for qualitative modelling

The environment was designed to be used by a wide range of students and in a variety of learning situations. This aim was tested by obtaining feedback from a range of potential users. Members of the Modus Club, a group of 140 educational institutions who were interested in obtaining information and/or exchanging ideas on modelling, were invited to view and use Expert Builder and were asked to complete a questionnaire.

1.3.6 The scope for qualitative modelling in the classroom

A detailed investigation was carried out in three primary schools using three classes in order to examine the use of Expert Builder in a normal classroom situation and to determine to what extent children are able to build computer based models. This work focused on the lower end of the user range which appeared to be about nine year-olds. The aim was to identify the scope, opportunities and limitations of qualitative modelling in a classroom setting. In particular the research aimed to determine how qualitative modelling could be integrated into the normal classroom learning environment.

1.3.7 Developing a mental model of the modelling metaphor

In Chapter 3 the theory of mental models is discussed and it is argued that an important factor in people's use of software is their development of a mental model of how the software works. This is discussed in relation to modelling systems and it is argued that it is only possible to make use of software for modelling if a person has an adequate mental model of the fundamentals of the modelling metaphor. The evaluation therefore aimed to attempt to elucidate children's mental models of the software although it is recognised to be very difficult to determine people's mental models. This was attempted through examining the models that pupils created and tried to create and the mistakes they made. Pupils were also tested on practical exercises using Expert Builder to determine their understanding of the fundamental working of the system. In this way the advantages and limitations of the modelling metaphor were elucidated.

1.3.8 Evaluating the user interface

Problems that pupils encountered when using the modelling system were analysed and this led to suggestions for improving the interface, some of which were implemented.

1.3.9 Analysing the modelling process

Very little is known about how people become skilled modellers and how to teach people to model, particularly younger learners. The definition of modelling outlined earlier placed the emphasis on a modelling process. An aim of this research was to examine how this process could be applied in the classroom and to elucidate the cognitive skills as well as other skills required and developed at each stage. Data from the classroom investigations was analysed with reference to several taxonomies of learning skills particularly Sternberg's componential subtheory (Sternberg 1985). This analysis, which is discussed in Chapter 9, enabled the identification of a list of the key skills and attitudes that teachers need to foster in their pupils in order to encourage the development of modelling ability.

During the research described here the national curriculum in England and Wales was developed and it included computer based modelling as one of the strands of information technology capability in attainment target 5 of the Technology Curriculum (Department of Education and Science and the Welsh Office 1990). The intended progression in modelling capability was examined with reference to the analysis of the modelling process, presented in this research, in order to compare the order in which skills and processes were expected to be developed.

1.3.10 Summary of research questions

The goal of this research, as stated earlier, was to find ways of using computers to enable learners to express and explore their ideas and understanding as qualitative models which they could run and evaluate. In section 1.3 the approach adopted for tackling this goal and the various issues that were investigated have been outlined. These can be summarised into the following main research questions:

1. Could children use a computer to build qualitative models on the topics that they were studying?
2. What modelling metaphor could be used that was sufficiently powerful to enable a wide range of qualitative modelling, at various levels, but was easy enough for inexperienced and younger pupils to begin to use in a short time?
3. How could the modelling environment be designed in order to enable users to develop rapidly a mental model of the modelling metaphor that would enable them to make use of the environment to build their own models?
4. How could this modelling environment be used in classrooms?
5. What skills and processes are needed for and developed by the modelling process?

All these questions have been answered by this research.

1.4 Timescale of the research

A diagram of the timescale of this research is given in Figure 1.1.

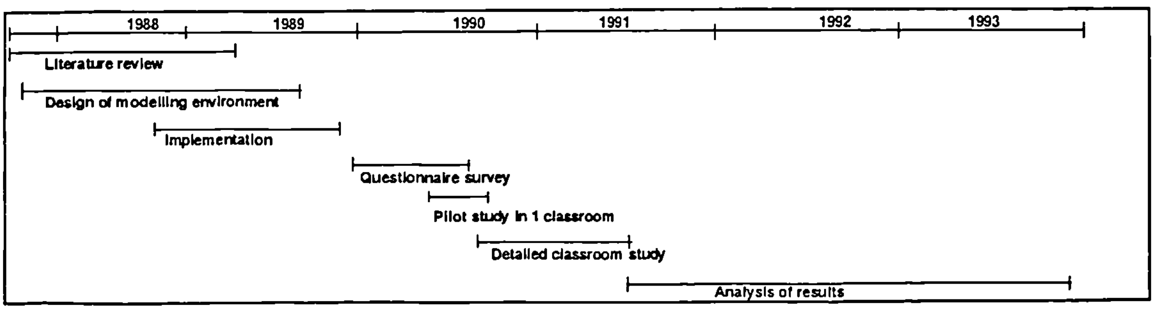

Figure 1.1 The timescale of the research

The literature review and design of the modelling environment were completed between January 1988 and March 1989. Implementation of Expert Builder was started in September 1988. The implementation of the rule storage structure and inference mechanism was carried out while the design of the user interface was still proceeding. Implementation was completed by October 1989. The initial evaluation study was carried out between November 1989 and July 1990. This involved the questionnaire survey of 140 educational institutions and the classroom pilot study. The latter took place in one primary school class with 17 pupils during the summer term of 1990. Data from this initial study was used to formulate questions for a detailed study as well as to identify schools to take part in the study. The detailed classroom study was carried out during the school year of September 1990 to July 1991. It involved one class from each of two primary schools throughout the whole school year as well as a class from another primary school during the summer term. Two teachers and 34 pupils were involved in the detailed study.

Chapter 2 A Review of Computer Based Modelling

In this chapter the modelling process is discussed. A description and diagrammatic representation of the process that is applicable to computer based modelling in a classroom situation is provided. This chapter also reviews computer based modelling systems that were available during the design stage of Expert Builder within the framework of a classification of modelling domains. This framework was devised in order to identify and characterise computer based modelling in schools. The strengths and weaknesses of these modelling environments, as tools for school pupils, were identified. Other relevant software that was developed simultaneously with this project is discussed in Chapter 10.

2.1 Approaches to modelling

The approach adopted, when constructing a model, may depend on the subject matter to be modelled and the modelling techniques to be used. In the physical sciences, modelling has been used for many years to elucidate specific and well defined problems such as loading and stress factors in a construction. In such situations the scope and boundaries of the problem are fairly easily identified and the techniques are well established. It may be possible to start constructing the model straight away with only brief consideration of the boundaries of the problem or the degree of resolution required. Resolution is used here, as described by Starfield and Bleloch (1986), to encompass the scope of the problem as well as the degree of emphasis ascribed to the components. Any particular system could be modelled at different degrees of resolution, e.g. the whole system could be modelled with the major components described quite generally with little detail or a particular part of the system might be modelled and specific components considered in much greater detail. In the biological, environmental and social sciences resolution is very important because the problems tend to be open ended and difficult to define. The systems under consideration are always open systems with many variables and it is generally necessary to focus on one aspect of a system or a subsystem that is really an abstraction from a much more complex situation. Starfield and Bleloch argued that the degree of resolution of a model depends on:-

- the purpose of the model
- the structure of the system
- the timescale of the model.

It therefore follows that a model must have a context i.e. the purpose must be clearly defined. Unless the purpose and resolution are defined the model could quickly become very complex and unmanageable. Consider for example a woodland ecosystem. There are many different species interacting with one another in various ways, including feeding relationships, competition for food and space and parasitism. A model of the whole system could be built at a low level of resolution, perhaps to model, for example, the overall energy flow through the system. However, if the primary purpose was to study fluctuations in the shrew population it would be necessary to identify the significant factors affecting the number of shrews and model those components at a higher degree of resolution.

There are risks associated with modelling in that it is relatively easy to miss important factors by drawing the boundaries too narrowly or tackling a complex situation in a fragmentary, uncoordinated way. It follows that there is a need to define a modelling process and perhaps a methodology for modelling that minimises these risks and optimises the chances of success as well as providing a framework for learning how to model.

Attempts have been made to define the modelling process in the context of mathematical modelling. One that has been particularly influential is the "seven-box diagram" (Open University, 1981).

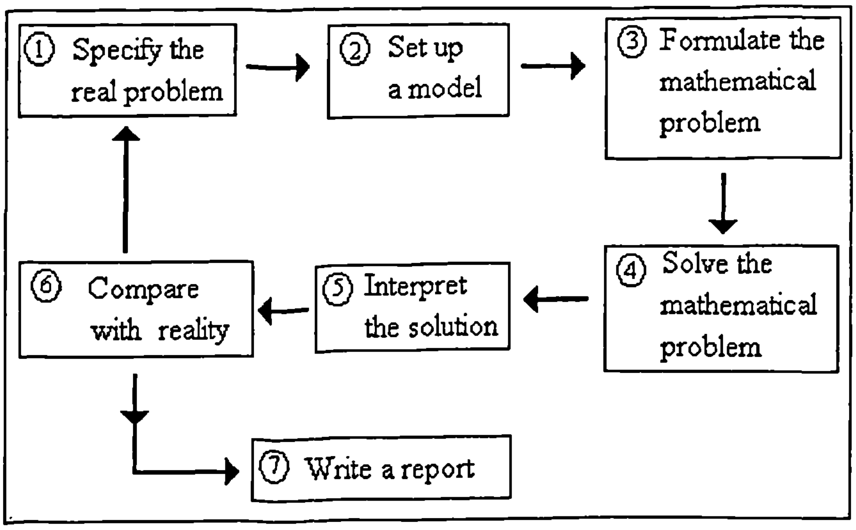

Figure 2.1 The seven-box diagram

This diagram (shown in Figure 2.1) describes some of the aspects which would be expected in any modelling process, such as specifying the problem and comparing the model output to reality but is based very specifically on mathematical modelling. The attention, in this approach, seems to focus on defining the correct mathematical model. The earlier stages in the process, when the problem is being identified and the purpose of the model is defined, deserve at least equal attention. The emphasis on mathematical problems is likely to appear threatening to teachers. Many teachers would shy away from "mathematical modelling", as they perceive it, even though they are confident to tackle the construction of decision-making models using a qualitative tool. This diagram may therefore not be adequate as a framework for learners undertaking modelling in a range of situations.

2.2 Applying the systems approach

General Systems Theory has led to some understanding of how to make the modelling process more effective by adopting more rigorous methodologies.

General systems theory claims to promote a number of new approaches to scientific study, including:-

- Organicism: living systems as a source of systems ideas
- Holism: the study of integrated wholes

- Modelling: the building of abstractions of the real world
- Understanding of processes in their own right.

A number of methodologies have been developed in order to facilitate the systems approach. The general aim of a systems methodology was to take an unstructured problem and produce a structured problem and solution strategy. One of the researchers in the UK who greatly influenced work in this field was Checkland (1981), who developed a so called "soft methodology" in which he recognised that real world problems may not have objective solutions. Checkland elucidated a seven stage methodology which is described here only briefly. In the early stages of problem definition he stressed the importance of developing a rich picture including complexity and not simplifying too much. The problem would be analysed and structures and processes would be distinguished. Relevant systems would then be defined by considering the components, inputs and outputs, transformations, and environment. Conceptual models would be developed using natural language as far as possible. The models would be compared with reality and then changes could be proposed. The aspects of Checkland's work, which are particularly significant to this discussion, are the rich description of the problem in the early stages, the subsequent structuring and the comparison of the models with reality.

Jeffers (1978) described how the systems approach could be applied to the modelling of ecological systems. He described the importance of systems analysis:

> *"The special contribution of systems analysis to problem-solving lies in the identification of unanticipated factors and interactions that may subsequently prove to be important, in the forcing of modifications to experimental and survey procedures to include these factors and interactions, and in illuminating critical weaknesses in hypotheses and assumptions."*

Jeffers mentioned particular problems in modelling ecological systems that could be overcome by adopting the systems approach including:

- overlooking some practical aspect of ecology which should be investigated
- failing to question widely held beliefs

- allowing the complexity of the problems to swamp the subsequent modelling
- becoming carried away by the elegance of the model and hence losing contact with the overall situation.

It is possible to imagine that similar problems might be encountered when modelling in other areas, and certainly Checkland considered his methodology to be widely applicable.

In summary, the systems approach offers a systematic, scientific approach to the solution of problems. Modelling carried out outside the context of the systems approach may increase the risk of encountering a number of problems including:

- failure to consider important factors
- modelling at an inappropriate resolution
- lack of a holistic view
- inappropriate boundaries to the model.

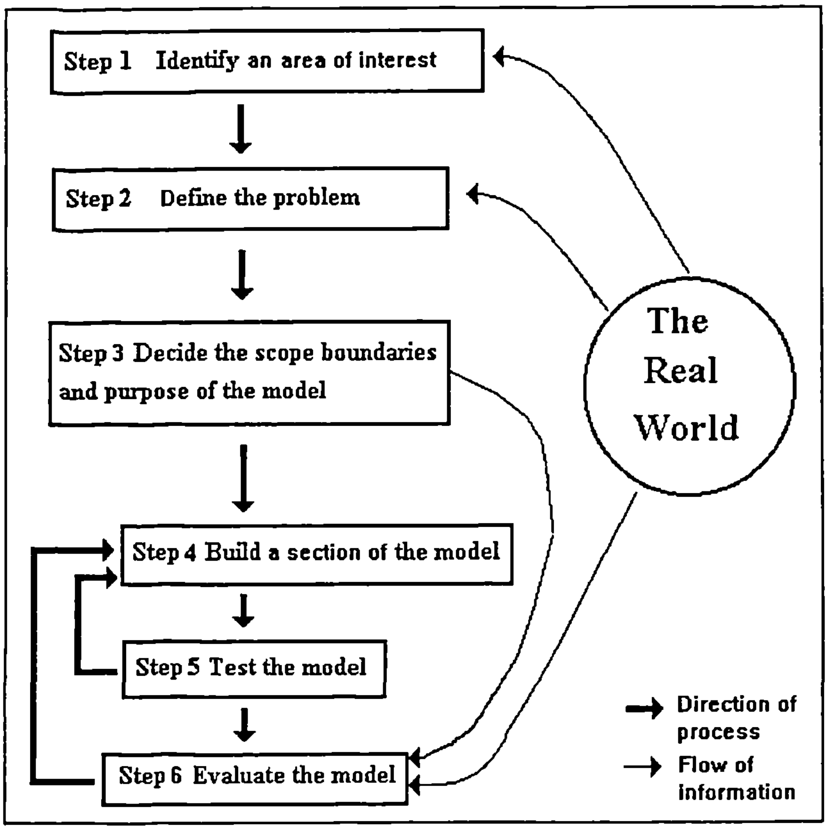

Figure 2.2 The Modelling Process

Any modelling task can be tackled as a structured process which is very similar to the systems analysis process. Figure 2.2 is a diagram of the modelling process as it might be undertaken by any modeller including learners who are making use of the modelling process. The stages are defined more fully in Table 2.1.

Table 2.1 Steps in the modelling process

Step 1 Identifying an area of interest

This is analogous to the first stage of Checkland's methodology in which he was concerned with developing a rich picture of the environment. However Checkland's methodology is specifically intended for systems analysis whereas although understanding any body of knowledge could be seen as a systems analysis task it is generally seen as a much broader activity. This first step in the modelling process may arise from any normal learning situation where the learner identifies an area where (s)he has an incomplete understanding or a complex situation which needs clarifying. This step is viewed as part of the modelling process because this places the process in a context just as Checkland's early stages establish the environment for systems analysis.

Step 2 Defining the problem

In this step a specific problem is identified from the area of incomplete understanding and some consideration is given to what needs to be known in order to solve this problem or to achieve greater understanding. A decision is taken as to whether there may be any benefit from constructing an external model. This will depend on the tools available, the learner's skills in using the tools and the learner's knowledge of the scope and benefits of modelling.

Step 3 Deciding the scope, boundaries and purpose of the model

In this step the nature of the model is outlined. It is important to be clear about the purpose of the model and how it is expected to be used. It may be intended to provide answers to "what if" questions or the intention may simply be to clarify a particular problem, in which case there may be no requirement to complete a usable model. It is also necessary to identify a suitable environment in which to create the model.

Step 4 Building the model

The model is built in stages. When the basic structure of the model has been planned the task can be split into sub-tasks and each part can be tested before proceeding.

Step 5 Testing the model

The model or part built models are tested with a range of different sets of data. If the model is considered to be fairly complete the modeller continues to step 6 but this would normally be after (s)he has repeated steps 4 and 5 a number of times.

Step 6 Evaluating the model

The model is evaluated by comparing its performance with its stated purpose.

This framework for the modelling process is based on the systems approach. It focuses on the importance of the early stages of the process as emphasised by Checkland and by Starfield and Bleloch.

This framework for the modelling process was discussed during seminars and courses run by the Modus Project. It was suggested that teachers should be aware of the whole modelling process. They should aim to introduce it to pupils so that they would eventually be able to carry out the whole process themselves. The framework was adapted for the Expert Builder manual and this is described in Chapter 5 (Section 5.9). The way in which the modelling process was applied in the classroom study is discussed in Chapter 8. This framework for the process was also used as the basis for the development of the taxonomy of modelling skills and processes discussed in Chapter 9.

2.3 Modelling Domains

In order to identify and characterise computer based modelling in schools, and to provide a way of talking about different types of models with teachers, during the feasibility study, a system of classifying models was devised (Webb 1988). Five modelling domains were identified on the basis of both the behaviour of the model and the methods of modelling:

1. Dynamic systems modelling
2. Spatial distribution modelling
3. Qualitative modelling using logical reasoning
4. Probabilistic event modelling
5. Data analysis modelling.

These groupings are abstractions from a continuum and were not intended to represent distinct and non overlapping divisions. This classification was developed during the Modus feasibility study in order to provide a framework for discussing modelling. It was used during discussions with teachers and their suggestions for modelling were categorised. This classification has also been used here to provide structure to this discussion. The class of qualitative models of logical reasoning were of most interest in this research because the aim was to develop a qualitative tool. It was not clear, at the outset, whether other types of modelling might also involve qualitative relationships or whether they might be adapted so that they could be tackled in a qualitative way. The provision of a qualitative tool was part of an overall plan to develop an integrated modelling system. It was possible that a qualitative metaphor might be identified that would support a wider range of modelling, thereby facilitating integration. Features of software for other types of modelling were also considered to see whether they could be used or adapted.

The remainder of this chapter will discuss the computer based modelling environments that were available during the design stage of this project and whose design principles and/or features were considered for possible adoption or adaptation for the design of the qualitative modelling environment. The software is described within the framework of modelling domains listed above, which is explained in more detail. In addition, two general purpose programming environments, LOGO and Boxer, are outlined because they have been used for modelling by school pupils.

2.4 Dynamic systems modelling

Dynamic systems are those where changes occur over time. In order to model such a system it is necessary to identify the variables and to define the relationships between them in such a way that the new values at a later time can be found. Mathematical techniques, which fulfil this purpose, include differential and difference equations. Computers have facilitated the use of iterative techniques for modelling such systems.

Engineering systems research provides a technique for describing dynamic systems by means of relational diagrams, using a set of standard symbols (Forrester 1961). State variables represent accumulations within the system of, for example, weight, numbers of organisms or energy. Rate equations govern the change of levels with time. When constructing such a model the first stage might be the construction of a relational diagram. This in itself is not sufficient, it is also necessary to specify the relationships explicitly using mathematical equations or computer algorithms. The rate equations would be differential or difference equations. The systems dynamic method provides great flexibility and freedom from constraints and assumptions. It is particularly suitable for coping with non-linearity and feedback loops. Models could be constructed to approximate as closely as possible to reality. However, according to Jeffers (1978), who looked specifically at using these techniques to model environmental systems, where these techniques have been advocated, freedom from constraints could also be disadvantageous for several reasons. First, the behaviour of even quite simple dynamic models could be difficult to predict, the incorporation of one non-linearity and two feedback loops would almost certainly result in the counter-intuitive behaviour of the model. Testing a model was an extensive procedure because it was necessary to vary more than one factor at a time in order to test it fully. Secondly an even more significant problem with dynamic models of environmental systems was the uncertainty of being able to estimate the values of basic parameters. Jeffers suggested that dynamic models may be helpful in the early stages of analysis of a complex ecological problem by concentrating attention on the basic relationships underlying the system and by defining the variables and sub-systems. However in the later stages of analysis he suggested that it may be more profitable to switch to another method of modelling.

A number of specific modelling languages were available for dynamic systems modelling at the research level, e.g. DYNAMO (1976). Several modelling packages were designed for education and were available for microcomputers including DMS (1985), STELLA (1985) and MICROMODELLER (1986). DMS enables users to specify relationships between variables and it then carries out an iteration automatically in order to generate new values at each time step. STELLA was based on the relational diagrams approach of Forrester. At the start of this work STELLA was considered, by the Modus Project Team, to be the most promising of these for school pupils, owing to its ease of use and graphical interface, and its facilities were analysed in some detail.

2.4.1 STELLA

STELLA (see Figure 2.3) was intended for use in research and higher education rather than schools, but the facilities provided by the Macintosh user interface make the software easy to operate. The system was designed to enable the user to investigate dynamic models that are built up as relational diagrams using predefined symbols that represent stocks, flows, regulators and auxiliary variables. Models can be constructed on the screen using a mouse to drag and position objects. The flows are controlled by regulators which in turn may be affected by auxiliary variables or by the stocks themselves. Once the diagram was complete the flows and variables could be defined in terms of equations using figures, the names given to the components in the system and the range of arithmetical and logical operators provided. An alternative method of input is provided where a line graph of the relationship could be drawn for any of the variables. The model could then be simulated over a determined time period and the results could be displayed in several ways. The diagram could be animated so that the levels of the stocks and flows would be illustrated. Time graphs could be drawn of any of the variables as well as scatter graphs of any two variables. A table of the results could be obtained for up to five of the components.

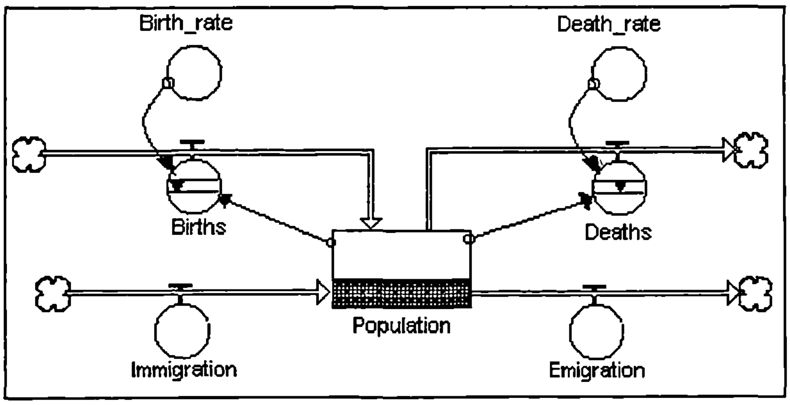

Figure 2.3 A simple model of population growth in STELLA

The important conceptual ideas required to make successful use of STELLA are those concerned with the systems dynamic approach and the ideas of flow and feedback. In order to construct a model in STELLA it is necessary to be able to interpret the system to be modelled in terms of the systems dynamics formalism. This is relatively easy if you are building a model of the hydrological cycle or nutrient cycling where material is clearly flowing through a system. It is much more difficult for modelling, for example, the growth of a population where the idea of materials flowing from a source to a sink do not appear to correspond to the problem being modelled. As Robertson et al. (1989) commented, STELLA permits only a solution to a user's modelling problem not a description of the problem. This would be an important limitation for pupils who were just beginning to develop modelling skills. Pupils need help in thinking about the problem to be modelled so an environment that requires them to make an intellectual leap in envisaging a solution in terms of a metaphor that bears no direct relation to the problem is unlikely to be helpful.

Some small scale trials were conducted with eight school pupils aged 13-14 in order to identify some of the strengths and weaknesses of STELLA (Webb, 1988 and Hassell, 1987). The diagrammatic interface proved to be useful for focusing discussion within the group and aided communication because pupils were able to discuss relationships between factors by pointing to the screen to clarify their verbal explanations. The need to specify variables as objects directed attention to important factors. Pupils had difficulty in distinguishing the different types of variables required by STELLA and they were unable to specify the mathematical relationships. The systems dynamic metaphor did help in enabling pupils to construct models of the hydrological cycle but seemed to confuse pupils when they were modelling the spread of disease.

The diagrammatic user interface of STELLA was a significant advance over other modelling software in that it did facilitate some modelling with school pupils although there were still problems in making use of the symbols available. Pupils found little difficulty in manipulating the interface and using the mouse controlled tools. This systems dynamic approach was rather complex for most school pupils below the age of 16. It was also a quantitative technique, rather than the qualitative approach that was sought, but opportunities for adapting the idea, by providing a "qualitative front-end" were considered and are discussed in Chapter 4 (Section 4.2).

2.5 Spatial distribution modelling

This is a broad group of models and a variety of examples were described by the teachers during the Modus Project's feasibility study. The group includes a variety of models in which the components are positioned or moving in space. These models were studied by the Modus Project (Webb and Hassell 1988).

2.6 Probabilistic event modelling

This style of modelling is based upon the representation of series of discrete events that depend on probabilities. The process of modelling in this domain would involve determining the events and their order and then assigning a probability function to each event. Production processes and queuing situations were placed in this category.

There were available at the time of this research a number of specialised modelling languages, such as Simscript (1985) that were used in research and industry. However their complexity made them unsuitable for use in schools. It was relatively easy to write simple probabilistic models in a programming language such as LOGO. Sellman (1987) experimented with constructing microworlds in LOGO for modelling genetics but in order to explore the basis of such models the user needed a considerable knowledge of LOGO. Such microworlds were very specific and didn't provide the facilities for working on a range of different topics.

This style of modelling was essentially quantitative and did not supply any useful ideas for the design of the qualitative modelling environment although it did become important in informing the design of Model Builder (Hassell and Webb, 1990) .

2.7 Qualitative modelling

Qualitative modelling involves specifying facts and relationships and the rules that govern the behaviour of the model. However the specification does not involve any quantification. Descriptions in words may be viewed as qualitative models but they lack the rigour and ability to be executed which was stated earlier as a requirement. One possibility was to use formal logic to express rules and relationships.

A number of techniques are applicable for this type of modelling including decision trees, decision tables, logic programming languages such as PROLOG (Bratko,1986) and expert system shells. Branching structures have been used for story builders and adventure game generators that provide facilities for model building. Some software has also been developed that enables modellers to describe dynamic systems using qualitative descriptions that were then interpreted by the software into a set of quantitative relationships (Robertson et al., 1989).

2.7.1 PROLOG

PROLOG derived its name from PROgramming in LOGic and is based on a branch of traditional logic known as predicate calculus. PROLOG is a simplified form of logic programming and includes only a limited type of logic. The law of classical logic implemented in PROLOG is modus ponens (if a then b; a therefore b). PROLOG allows the user to specify facts and rules and to ask questions. The user could tell PROLOG what (s)he knew and PROLOG would determine whether a specific conclusion could be reached using its inference mechanism.

The strategy is described as backward chaining because the computer identifies the goal attribute and finds rules that lead to that goal, e.g. this rule set:

> 1 animal is insect if animal has 6-legs.
> 2 animal is arthropod if animal is insect.
> 3 animal is invertebrate if animal is arthropod.

would appear in a PROLOG program as:

```
insect (x) :
has (x, 6_legs).
arthropod (x):
insect (x).
invertebrate (x):-
arthropod (x).
```

A user might supply the fact, "fly has 6-legs" and ask the question "Is the fly an invertebrate?" This question would be matched to the attribute in rule 3, "animal is invertebrate", which would become the goal attribute. PROLOG would look at the condition(s) that needed to be satisfied in order to verify that goal and find only one - "animal is arthropod". This would become a sub-goal and PROLOG would look back to see what condition(s) needed to be fulfilled to verify that goal, etc. In this example

PROLOG would chain back from rule 3, through rule 2 to rule 1. These rules contained only simple clauses but it would be possible to use the logical connectors, AND and OR to formulate multiple conditions.

The example above contains only a very small rule set but if there are a large number of rules it is necessary to have a control structure to decide the order in which rules are checked. The structure in PROLOG is described as a hierarchical state-space search because there are a finite number of states that can be reached under a fixed set of rules. This can be represented by an and/or tree structure as shown in Figure 2.4.

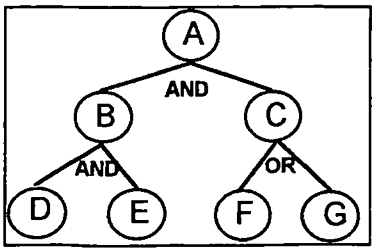

Figure 2.4 The AND/OR tree structure of PROLOG

The preceding discussion explained the logical basis of PROLOG; in addition, PROLOG has powerful list processing and pattern matching facilities that allow complex databases to be constructed.

An important feature of PROLOG is its declarative nature. Knowledge can be entered as facts and rules and so it would be possible, when programming, to describe a problem rather than specifying how the problem was to be solved. This opens up new problem solving possibilities and considerably alters the way in which the computer and user interact because the user can concentrate on the nature and precise definition of the problem and leave the computer to work out an algorithm for its solution. Procedural programming is also available in PROLOG and is used for serious applications where additional facilities are required.

It is relatively easy to write PROLOG programs that manipulate other programs, either written in PROLOG or in other languages. This would make it possible to build front ends on to a variety of applications.

PROLOG was advocated as a logic programming language for children as early as 1980 when Kowalski set up a project at Imperial College to investigate children learning PROLOG (Ennals 1983). However there has been no widespread adoption of PROLOG in schools. Two major problems with the adoption of PROLOG in schools are the relatively complex syntax and the lack of graphics. Scherz (1987) reported the incorporation of PROLOG into the curriculum in Israel but her investigations showed that PROLOG was only suitable for children aged 14 and above in the top 50% of the ability range. The syntax problem has been addressed by front ends to PROLOG such as MITSI (Man In The Street Interface), a version of which was in use in Danish schools (Borgh and Skardhamar (1987)). Cumming and Abbott (1988) reported work using MITSI where they found that the lack of graphical facilities was a significant drawback. In another study using SIMPLE, another front end to PROLOG, Light et al. (1987) found that the syntax, which is close to natural language, caused the pupils to forget that they were using a very formal and precise programming language and to lapse into English when entering their commands.

A tool developed by Eisenstadt and Brayshaw (1986), which provides a graphical view of a PROLOG program, is the Transparent PROLOG Machine (TPM). This is a sophisticated graphical tracing and debugging facility for PROLOG that uses "AORTA" diagrams (AND/OR Tree, Augmented). It is possible to display an execution space of several thousand nodes on a graphics workstation by making use of a "long distance" view. A zoom facility can provide close-ups. The tree is described as augmented because the nodes consist of "status boxes" that indicate whether or not the goal has succeeded and which clause is currently being evaluated. The TPM is intended to help teach novices to learn PROLOG as well as being a tool for experienced PROLOG programmers. This tool was aimed at undergraduates rather than school pupils but the approach might also be applicable at a lower level.

In summary, the implementation of logic programming in PROLOG is not suitable for the qualitative modelling envisaged in this research because it is too complex for most school pupils but the Transparent PROLOG Machine did suggest a way in which logical structures might be presented to users.

2.7.2 Expert System shells

An expert system is a knowledge-based system that solves and gives advice on problems of limited scope with approximately the same degree of accuracy as a human expert. Typically the system consists of a knowledge base and an inference engine as illustrated in Figure 2.5.

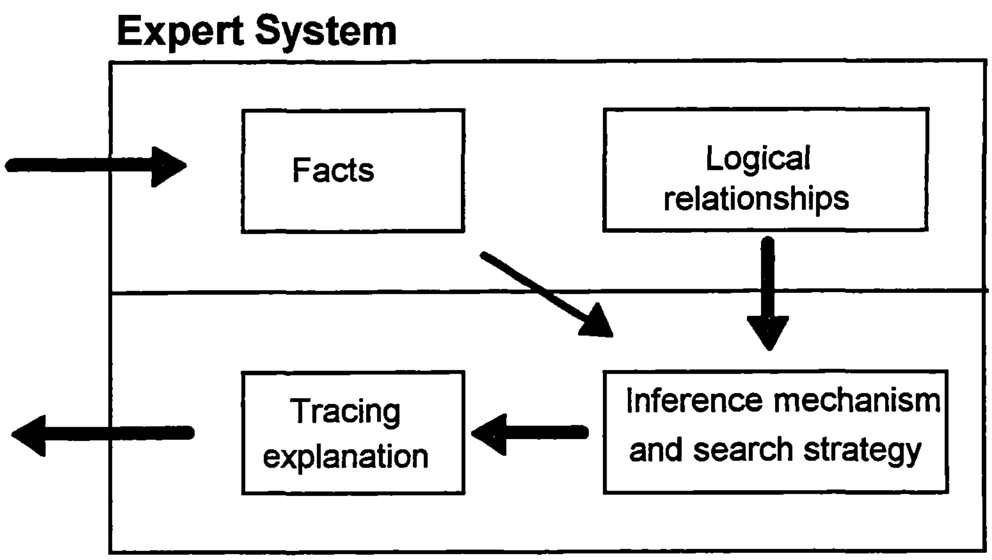

Figure 2.5 The parts of an expert system.

A range of shells are available for business and industrial use. They allow more rapid construction of expert systems than could be achieved using a programming language.

Expert systems built by commercial organisations include fault diagnosis, financial advice and planning systems. They typically consist of several hundred rules and would take a team of two or three people several months to build.

The facilities of expert system shells will be discussed here with particular reference to their possible use by pupils. Since the primary objective was for the pupil to take the place of the knowledge engineer, the most important features were those which aided the construction of the expert system.

The knowledge representation formalism in the majority of expert system shells is "IF - THEN" rules with the following format:-

IF (premise) THEN (conclusion)

Complex rules could be constructed using Boolean connectives. IF - THEN rules were claimed to be a natural representation for expert knowledge and this is probably true for certain types of knowledge. Empirical associations and problem solving activities could be expressed in this way and hence decision-making and diagnosis have been successfully modelled using rules. Investigations of cause and effects could be carried out and could involve chains of reasoning. Most expert systems can only model a process at one point in time as a result of the monotonicity of their reasoning mechanisms. Therefore they would not be appropriate for situations that involved changes over time. When a user questioned an expert system the user would provide data which was correct at that time and the system would reason using that data. At a later time the data might change but the system would be unable to reverse the reasoning that had taken place.

Another knowledge representation formalism that is frequently provided for expert systems is the frame (Aiken 1983 and Stefik 1979). In a frame the properties of an object or event are organised together in a group and the frame can be accessed and processed as a unit. A simple example is shown in Figure 2.6. Each frame has a name that identifies the concept that describes it and it is made up of a set of descriptors, termed slots. The spaces could be filled by objects that represent the current values of the slots. A "specialisation of" slot could be used to set up an inheritance hierarchy.

Frame name	INSECT
specialisation of:	Arthropod
name:	pond skater
habitat:	pond surface
food:	insects

Figure 2.6 Example of a frame

A slot filler could be a constant or the name of another frame. In addition the labels, "unit" and "range" could be used to restrict the type of object. Unit specifies that certain objects are required and range specifies the set of objects from which one must be selected. It is also possible to embed procedures in frames so that a slot is filled with a call to a procedure.

Frames can be thought of as specialised tables and they provide a powerful formalism for knowledge representation. Their main limitation as a mechanism of knowledge representation for children to use is that their great flexibility is likely to make them complex to use.

When building an expert system, the knowledge engineer has to carry out a number of disparate but necessarily interconnected tasks, including knowledge elicitation, domain understanding, domain representation and validation. Since knowledge engineering is a relatively recent enterprise, there are no adequate theories about how to carry out such tasks. Rather than implementing a particular theory, most expert system shells, provide a set of tools to help the knowledge engineer in her/his task. Much assistance is given at the domain representation level, by providing representational formalisms, and at the validation level, by providing good editing, debugging and tracing facilities. However, little support is given, in the majority of expert system shells and tool kits, at the knowledge elicitation or domain understanding levels.

Briggs (1987) built several shells with more limited facilities that were intended for use in further education to explore the scope and facilities of expert systems. It is difficult to build a knowledge base unless goals are specified in advance and different types of system, e.g. diagnosis, advice or planning, require different facilities. Briggs approached the problem by providing several different shells each of which was more suitable for some purposes than others. One of these shells, Adex-Advisor was considered in some detail since it had been trialled in schools and it represented one of the most promising expert system shells that was available for educational use. The features of Adex Advisor will be discussed in Sub-section 2.7.2.2.

In the next sub-section types of expert systems are briefly considered in order to clarify the range of types of models that could be built.

2.7.2.1 Types of expert system models

Expert systems have been developed in business and industry for various different purposes including advising on how to solve problems or analyse results, diagnosing medical conditions or faults in equipment, identifying or classifying objects and assisting in planning (e.g. Harmon and King 1985). Four different types of models were identified, which required different approaches and, in some cases, different software facilities.

- advice models
- diagnostic models
- classification models
- planning models.

When building an advice-type of model, the builder would generally identify a number of pieces of advice which might be given to the person using the system. (S)he would then go on to specify the conditions under which each piece of advice would apply. A diagnostic model would attempt to analyse the reasons for an observation or to explore cause and effect. The model would probably be built by starting with the effects and considering the possible causes. A classification model would specify the key criteria for particular taxonomic groups. The modeller would consider each group in turn and specify the criteria as rules or frames. A model intended for planning and designing would generally be constructed by starting from the constraints and needs and working towards suggestions about various aspects of the design. It could result in a large number of conclusions.

The facilities needed for these different types of expert systems are discussed in Chapter 4 where the features of expert system shells are discussed in more detail in relation to the requirements of the modelling metaphor for Expert Builder.

2.7.2.2 ADEX-Advisor

ADEX-Advisor was developed as a simple expert system shell for pupils to build and explore advice-type expert systems. It runs on the Nimbus and IBM PC and operates via a menu system where the commands are selected by keying in the first letter. The program has a simple editor that uses the cursor keys and the delete key. A knowledge base would be constructed in ADEX-Advisor by typing in a series of textual rules that form the basis for the model. Statements providing advice and rules would be entered in the following format:

conclusion if premise1 and premise2

Considerable care has to be taken as exact pattern matching is required for the system to work. The most recent version of Adex-Advisor facilitates this by allowing the user to select a premise from the rules, already present, to become the conclusion of another rule. The logical operators AND and NOT can be used in the second clause of a rule but OR can only be implemented by using separate rules. The program uses the inherent backward chaining inference mechanism of PROLOG to make deductions from the rules. When the end of a chain is reached and no more can be inferred without more information, the system asks the user a question. In order to improve efficiency, at this point the system checks for other questions with similar wording and combined several questions together, thereby maximising the information obtained from one answer, e.g. these two rules:

the disease is infectious if
the disease is spread by droplet infection
the disease is infectious if
the disease is spread by skin contact

would produce the following question:-

Is it true that the disease is spread by
droplet infection
skin contact

Any number of the possible answers could be selected. Eventually, if the logic was correct and complete, the user would be given the correct advice.

In summary, expert system shells showed some of the features that were required for a modelling metaphor in that they facilitated qualitative modelling and it had been possible to produce a simplified version of this environment for use in schools. Empirical studies of using this software are returned to later in Chapter 4 (Section 4.2) where the suitability of an expert system shell for the modelling environment is discussed in detail.

2.7.3 Story builders

Software that enabled branching stories to be created have been used in schools for some years, e.g. Stopress enables users to create Viewdata pages and link them into a branching database or story. LINX88 (Briggs, Brough, Nichol and Dean, 1988) provides more sophisticated branching facilities although it lacks graphic facilities. In LINX88 a page of textual description could be input for each event and then events could be linked together. Rules could be input to control movement between events. This software enables the construction of adventure games and event-based simulations such as voyages of discovery. This type of software is on the borderline of the definition of modelling software. Where it consists of pages of text with simple links, it cannot be described as a modelling environment because there is no formal representation mechanism and there is no way of running the model but where the links are governed by rules it is possible to build a model where formal rules govern the way the scenario will unfold when it is run. None of these story-builders provide a diagrammatic view of the structure of the story and it was found in use that teachers encourage pupils to produce a diagram on paper or as a wall chart to assist in structuring the story. This type of software provides some modelling opportunities and it has been used by children so it is returned to in Chapter 4 where it is considered in relation to children's modelling needs.

2.7.4 Qualitative modelling using weighting factors

Some programs that have been developed for educational use enable the user to construct a model that analyses the problem and supports the decision making process by using weighting factors to compare the key factors in the problem. Two programs that operate in this way and have been used in schools, were "Route" that considers the problem of selecting a route for a new motorway and "Choosing sites" that focuses on siting a new development such as an airport or a supermarket. "Choosing sites" is applicable to a range of problems. A number of site descriptors can be input together with number of factors affecting the choice of site. A matrix is then set up showing the value of each factor at each site as a number from 0 to 10. The factors can then be ranked and hence given weightings. For each site an overall numeric value can then be calculated. The program enables new scenarios to be created but this facility is intended primarily for the teacher. The program allows the pupil to rank the factors. This kind of modelling could also be done using a spreadsheet. It provides a way of making quantitative comparisons based on qualitative factors. The use of "Choosing sites" could stimulate discussion and does enable some modelling although it was quite difficult to set up new scenarios. The possibility of incorporating this approach with other styles of qualitative modelling is discussed in Chapter 4 (Section 4.3.5).

2.7.5 Qualitative environments for dynamic modelling

The ECO-project (Robertson et al. 1989) set out to provide a friendly user interface as a front end to a simulation language so that the user could express the ideas for her/his model in a logic-based language. This could then be translated into the mathematical relationships required to make the model run. This language was intended for ecologists and set out to enable a wider range of input and output expressions than were permitted in the systems dynamics approach. They had considered using the systems dynamics approach and implementing a relational diagram but this would have been too restrictive given the range of expressions that the ecologists linked to the project wanted to use. The ECO-project experimented with a number of systems including an interface that enabled users to build up an executable program by constructing a tree of sub-models and the use of template logic sentences from which users must select those applicable to their models. The ECO-project was only attempting to provide facilities for the construction of a relatively narrow range of models focusing on ecological systems but Robertson et al. reported a number of problems in trying to provide these facilities. In particular they found that providing flexibility of input expressions caused a disproportionately large set of problems in the user interface.

This approach, then, was a way of providing facilities for dynamic modelling through qualitative expressions. It had advantages in that it would enable a range of dynamic models to be built but the trade-off between flexibility of input and ease of use was likely to be problematic. Nevertheless this did offer another possible approach and it is discussed further in Chapter 4 (Section 4.2).

2.8 Data analysis modelling

These models are applied to data in order to identify patterns. They are most useful where the data contains many variables and in these cases multivariate models are used but a number of other simpler statistical techniques might be used to fit models to data.

There are a number of multivariate modelling techniques including principal component analysis, cluster analysis and reciprocal averaging. Most of these methods use matrix algebra and the large amount of processing required when dealing with many variables means that they can only be done effectively by a computer. A number of packages are available for use in research but none have been designed to be sufficiently easy for school children to use.

Although this style of modelling was felt to be desirable as part of the whole Integrated Modelling system for the Modus Project, it did not present any implications for the development of the qualitative modelling facility.

2.9 LOGO and Boxer

These two programming environments were considered because they have enabled children to do some modelling. They are discussed outside the framework of modelling domains because they could be used in any domain. LOGO was mentioned previously in relation to probabilistic event modelling where it had been used by Sellman (1987) to construct a genetics microworld to enable the construction and exploration of genetics models. LOGO has all the capabilities of a general purpose programming language and hence could be used for any type of modelling. This great flexibility meant that significant programming effort was required to construct most models. The most common use of LOGO in schools was using the turtle microworld to explore and model mathematical ideas particularly in geometry. Empirical studies using LOGO are discussed in Chapter 3 (Section 3.9.2). One possible approach to developing modelling environments was to provide tools within LOGO to facilitate the construction of various types of models. This might enable teachers and children to build on their work with LOGO. This idea was rejected for two main reasons. First the predominant use of LOGO in schools was limited to the turtle graphics microworld, indeed many schools were using cut down versions of LOGO that only provided turtle graphics. Therefore, although LOGO was widely used, its use was restricted to a small subset of the facilities so teachers' and children's familiarity with the LOGO environment would be limited. Secondly the user interface of LOGO was no more friendly than any standard programming language. It did not have easily manipulable graphically based facilities for editing programs such as those provided by STELLA.

Boxer was developed as a programming language for children (DiSessa and Abelson, 1986) in order to overcome some of the limitations of the user interface of LOGO, while providing enhanced programming facilities. DiSessa and Abelson described two key principles on which the design of Boxer was based. First the spatial metaphor was the basis for the organisation of the computational environment. All computational objects were represented in terms of boxes, which were regions on the screen that could contain text, graphics or other boxes. Secondly the design embodied the principle of "naive realism", an extension of the "what you see is what you have" idea that has become common-place with text editors and graphics programs but not with programming languages. The principle is that users should be able to pretend that what they see on the screen is their computational world in its entirety. For example any text that appears on the screen, whether produced by the system, entered by the user, or constructed by a program would be able to be moved, copied, changed or, if it is program text, evaluated. Similarly the value of a variable would be able to be changed simply by altering the contents of the variable box on the screen.

Boxer provides a powerful programming environment but it was implemented on powerful work-stations and so could not be used in most schools at that time. Therefore there was no possibility of implementing the modelling environment in Boxer.

The principle of naive realism represented a step forward in the design of programming environments, which was particularly appropriate for young learners. In relation to the modelling environment this would mean that the metaphor would need to be fully representable in a graphical or pictorial view on the screen. Users would be able to interact with this view so that, for example, any changes that they made to their model would be made directly on the model on the screen. The model would also be run through the same screen view. Users would therefore be able to feel that they were in control of the environment and that the behaviour of the model was entirely the result of the way that they had designed it. This was desirable because any suggestion that the model's behaviour might be due to unpredictable and uncontrollable features of the behaviour of the environment would be likely to confuse and demotivate modellers.

2.10 Conclusions

During the design stage of this project only a limited number of modelling environments were available and only very few of these showed any potential for use in schools. Those that informed the design of Expert Builder were PROLOG, expert system shells, the Transparent PROLOG machine, the Eco-project software, STELLA and Boxer. STELLA revealed the scope and limitations of the systems dynamic approach. This approach has limitations for ecologists in that they must first define the solution to the problem in terms of this metaphor. Trials with school pupils showed that understanding and making full use of this metaphor was beyond all but the more able advanced-level students. The diagrammatic interface was useful for focusing discussion and aiding communication. This suggested at the time that one possible approach might be to provide the diagrammatic interface of STELLA for starting modelling. STELLA enables models of most dynamic systems to be developed, including environmental, physical, economic and physiological. The basis of STELLA is clearly quantitative but in the initial stages of building the model, users can simply connect the variables with arrows to show that one variable affects another. This stage was within the capabilities of secondary school pupils although the different types of variables caused confusion. Pupils tended to use just one type of variable. One possible approach might be to provide a simplified version of the relational diagram so that users could explore qualitative relationships between variables and then the system could compile these into an executable model. At the compilation stage some kind of quantitative relationships would need to be specified by the system. The work of the Eco-project suggested that providing a qualitative rule-based user-friendly interface for dynamic modelling that would enable the creation of a wider range of models would be very difficult because there seemed to be a trade-off between flexibility of input expressions and ease of use.

PROLOG and expert system shells, although too complex in their existing form for use by school pupils, could provide a metaphor for qualitative modelling that would be very flexible and enable modelling in a wide range of subject areas. The modelling of decision-making and problem-solving that these environments support has very wide applications. AORTA-type diagrams, similar to those used in the Transparent PROLOG machine could be used as a front-end.

The principle of naive realism became a key design principle for the modelling environment.

This survey of existing software confirmed that there was no suitable qualitative modelling environment available for this research but revealed two strong candidates as possible metaphors for a new environment. The first involved a relational diagram based on the systems dynamics approach and the second was a rule based metaphor similar to that used in PROLOG and some expert system shells. The second approach can be described as truly qualitative but the first requires some quantification in order for the model to run. Empirical studies had shown that both of these metaphors had some potential for use by children. In addition, several other possible metaphors were identified including "story-builders" and a frame-based metaphor. As well as examining the practical possibilities, the research for the design took into account how children learn and these issues are discussed in Chapter 3. In Chapter 4 the metaphors, which were discussed in this chapter, are considered in relation to the needs of learners and teachers.

Chapter 3 Learning and Modelling

One of the principles of the Modus Project was that while learners are engaging in computer based modelling they are facilitating their own learning. The Modus Project suggested that this might occur in three main ways. First, building models may help children to learn about a topic. Secondly the process of modelling may enhance learners' understanding of the subject being modelled more than other learning methods. Thirdly modelling may assist in the development of more general problem solving skills. The first two of these proposals were particularly important because they provided a justification for developing computer based modelling across the curriculum rather than assigning it to a slot within an information technology course. These proposals were based upon classroom experience but were also compatible with the constructivist approach to learning. In this chapter this constructivist approach to learning is reviewed and its theoretical basis is examined. Other relevant theories and empirical evidence are also reviewed in order to inform both the design of tools for computer based modelling and the way in which such tools might be used.

3.1 The constructivist approach to learning

During the 1980's there were strong movements, in both mathematics and science education in the UK, towards a constructivist approach in which learning is viewed as a process of knowledge construction. The essence of this approach was that students were perceived as active learners who already held a set of concepts which they used to make sense of the world around them. This view is associated with Kelly (1971) and given emphasis by Driver and Easley (1978). A study by Clough, Driver and Wood-Robinson (1987) indicated that school pupils do have alternative conceptions in a wide range of topic areas in the physical and biological sciences and that these tend to persist despite schooling. Osborne, Bell and Gilbert (1986) concluded, from a number of studies, that children's viewpoints are largely uninfluenced, or influenced in unanticipated ways, by much of science teaching. They argued that we need to design curricula which would build on, rather than ignore, children's views. In mathematics education constructivism provides a way of perceiving teaching and learning and is consistent with recent changes in teaching methods (Jaworski 1988). In science education, the constructivist approach in the UK has led to a "generative model" of learning (Osborne and Wittrock, 1985). This model proposes that people tend to generate perceptions and meanings that are consistent with their prior learning.

The Children's Learning in Science Project (CLIS 1987), has developed teaching strategies and learning materials and has defined a constructivist learning sequence as follows:

1. An orientation stage where children focus their sense of enquiry on to a particular science issue.
2. Elicitation of children's ideas which is initiated by:

   a) enabling the students to recognise their own everyday ideas that relate to the situation being studied

   b) encouraging the students to verbalise their everyday ideas

   c) helping to make the teacher become aware of the range of pupil ideas.
3. Restructuring children's ideas by providing appropriate learning experiences.
4. Application of new ideas in a range of contexts.
5. Encouraging children to review their own learning.

Modelling could be valuable in this teaching sequence at both the elicitation stage where it would enable children to express their ideas and at the application stage where pupils could build models which took account of their new ideas. The intended application of the proposed modelling environment, however, extends beyond the mathematics and science curriculum as does constructivism which is a philosophical stance about the nature of learning.

The constructivist approach to learning has been influential in education in the UK, particularly in science education. The CLIS project is influential at secondary school level. The SPACE (Science Processes and Concepts Exploration) project has researched younger children's understanding of scientific concepts and promoted a constructivist approach at primary school level.

3.2 Constructivism

Constructivism embodies a philosophical view that according to von Glaserfeld (1989):

> *"discards the notion that knowledge could or should be a representation of an observer-independent world-in-itself and replaces it with the demand that the conceptual constructs we call knowledge be viable in the experiential world of the knowing subject." (p122)*

Von Glaserfeld is one of the principal exponents of *radical constructivism*, a philosophical position which, in addition to claiming that knowledge is actively constructed also discards the notion of knowledge as correspondence with an objective reality. The constructivist approach to teaching and learning developed as a result of observations of children's learning. As Driver (1986) stated:

> *"It would be incorrect to suggest that psychologists and philosophers of science have been influential in shaping the science in our schools. Rather the community of science educators has invoked such theoretical 'support' as is necessary to give credibility to 'common sense' views about the nature of science and of children's learning." (p270)*

Nevertheless Driver and Oldham (1986) appeared to accept the position of von Glaserfeld since they listed as an implication of the constructivist perspective:

> *"We cannot 'check' our knowledge against an external reality. Our only check is the extent to which our constructions fit with our experience in a coherent and consistent way." (von Glaserfeld 1983)*

Von Glaserfeld acknowledged the essentially empirical foundations of the constructivist approach to learning and teaching when he stated, in conclusion to his account of the theoretical basis of constructivism:

> *"Good teachers have practised much of what is suggested here, without the benefit of an explicit theory of knowing. Their approach was intuitive and successful, and this exposition will not present anything to change their ways.*

But by supplying a theoretical foundation that seems compatible with what has worked in the past, constructivism may provide the thousands of less intuitive educators an accessible way to improve their methods of instruction." (p138)

Von Glaserfeld claimed that Piaget was the most prolific constructivist in the twentieth century. Piaget put forward the idea of the learner as an active constructor of her/his knowledge. He suggested that there are four factors influencing a child's intellectual development (Piaget and Inhelder 1969):

1 Organic growth

2 The role of exercise and of acquired experience in the actions performed upon objects including both direct physical experience and indirect logico-mathematical expression.

3 Social interaction and transmission

4 Equilibration.

The idea of equilibration was particularly important in Piaget's ideas. In "The development of thought" (Piaget, 1978 pp 178-184), he described the development of knowledge as consisting of a sequence of successively improving forms of equilibrium. He identified 3 levels:

1 between the subject's mental schemes and external objects

2 between mental sub-schemes coordinated into an overall scheme

3 differentiation and integration of schemes or systems into a total system of knowledge, qualitatively different from parts, e.g. construction of a conceptual model or theory.

This summary of Piaget's version of constructivism is included here because it has been very influential in education in this century rather than because it embodies all of the constructivist theory. Von Glaserfeld argued that Piaget was a radical constructivist:

"Knowledge for Piaget is never a 'representation' of the real world. Instead it is the collection of conceptual structures that turn out to be adapted within the knowing subject's range of experience" (p125)

O'Loughlin (1992) argued that many constructivists base their pedagogy exclusively on Piagetian theory, including the "stage theory of development". Much of the emphasis of Piaget's work was on the natural development of the child, a development that takes place, according to Piaget, within an intrinsic framework of stages. The child, through her/his actions in the natural world, evolves her/his cognitive structure. In Piaget's view the maximum rate of cognitive development is limited by ontogenetic factors and children progress through stages of development. A detailed consideration of this aspect of Piaget's work is not necessary for this discussion because it is the active construction of knowledge which is particularly significant for computer based modelling and this is not dependent on the stage theory. The stage theory of development has been called into question by more recent research, particularly evidence of the importance of context in cognitive development (e.g. Donaldson, (1978), Carey, (1985a), Keil, (1986)). Their work contradicts the existence of universalist, hierarchical stages of development across various domains. The importance of context in cognitive development is discussed further in the next section.

O'Loughlin argued that a constructivist approach, based on Piagetian theory, gives primacy to abstract mental structures and rational thought at the expense of the historically and socially constituted subjectivity that each person brings to the reasoning process.

The Piagetian constructivism criticised by O'Loughlin is very different from that promoted by the CLIS project which does recognise the importance of social context. Driver and Oldham (1986) emphasised the importance of learners expressing their present knowledge and beliefs. They stated that individuals construct knowledge through social interaction and experiences with the physical environment. They also considered the importance of context in children's learning and did not adhere to Piagetian stage theory. This constructivist approach to learning could make use of learning activities which involve modelling. A model has been defined as a representation of some aspect of the real world. The modeller must access her/his conceptual structures to build the model. Building the model is a test of how well adapted those conceptual structures are to the task of representing this aspect of the world given these tools. Success in the modelling task, as measured by some specific predefined criteria about the purpose and accuracy of the model, is likely to depend on:

- how well the person's conceptual structures are adapted to provide the relevant information for the task
- how well the person is able to recognise and extract their own relevant knowledge
- how appropriate are the tools for expressing this knowledge.

The model would not necessarily be an analogue of the real world. It would be a representation of some aspect of the world in that it would be expected to provide an output that was consistent with the behaviour of a part of the real world even if that was a human decision making process. The model building process could encourage the learner to use her/his knowledge and perhaps evaluate it in terms of how well adapted it was. This would be dependent on the learner testing her/his model against real world data otherwise it would simply be based on the learner's untested knowledge. In addition the learner could compare her/his model with models built by others including the teacher. The main message for the design of a computer based modelling environment was that it needed to facilitate the expression of the learner's knowledge as well as permit the representation of the relevant aspect of the real world, for example differential calculus would enable the representation of the behaviour of dynamic systems but it would only facilitate the expression of knowledge for competent mathematicians. Since the modelling environment, in this project, was intended for young learners it needed to help them express their knowledge by making the transformation of that knowledge from their own mental representations to those of the modelling environment as easy as possible.

3.3 The importance of context in cognitive development

There is a debate in progress about the importance of domain-specific and domain-general knowledge and skills. Does cognitive change affect all domains of knowledge simultaneously or does development occur in a domain-specific fashion? Piaget's stage theory of development asserts that cognitive development is domain-general but more recent studies have provided evidence to challenge this view. Donaldson (1978) reported studies by a number of researchers who devised tasks for preschool children which required the same abilities as those that were central to Piaget's stage theory of development, e.g. the ability to decentre and the ability to make deductive inferences. The major difference between these tasks and those used by Piaget was that the former "made sense" to children. The setting and characters were designed so that the children grasped the nature of the situation and understood the motives and intentions of the characters. Children performed well on these tasks showing abilities that Piaget had claimed were not present in children of this age.

There are now a number of studies which suggest that children can demonstrate cognitive abilities in some contexts but are not able to use them in others e.g. Carey, (1985a), Keil, (1986).

Carey (1985b) (p194) stated that there was some consensus, contrary to Piaget's view, that the pre-school child appreciates mechanical causality. She claimed that human beings are theory builders so that from the beginning we construct structures that help us find the deeper reality underlying surface chaos.

Carey conducted empirical studies of the restructuring of the children's knowledge of living things between the ages of 4 and 10. She concluded that this restructuring critically involves changes in causal explanation that are specific to the domain. The 4-7 year-old attributes what for adults are biological phenomena in terms of psychological causal notions, e.g. the frog jumps into the pond because it wants to swim. By age 10 the child has constructed a system of biological explanation as well. The crucial point, according to Carey, is that development of explanatory frameworks is part and parcel of theory changes - not domain general. The work of Carey and others, which she cites, provides evidence against the Piagetian claim that immature notions of causality, in general, place any domain-independent constraints on the conceptual structures of children of young ages. These findings are relevant to the design and use of a qualitative modelling tool for two main reasons. First, use of the tool would require reasoning skills, which according to Piaget, were not available to young children. This issue is discussed in Section 3.7. Secondly, much of the research on children undertaking computer based modelling has been carried out using LOGO. The development and use of LOGO has been strongly influenced by Piagetian theory. There is controversy about claims for the beneficial effects of children using LOGO on the development of general cognitive skills. These issues are discussed in Section 3.9.2

3.4 Mental models

The ideas of the mental models field have emerged from the intersection of two areas of research, cognitive psychology and artificial intelligence. Artificial intelligence has provided powerful formalisms for expressing theories of human knowledge representation and processing. The mental models approach to cognition is associated with Johnson-Laird (1983), De Kleer and Brown (1983) and Norman (1983). This school of thought proposes that people construct mental models of everything with which they interact. While they were working with a modelling environment, for example, users would construct mental models of the situation they were modelling and also of the modelling environment itself. Johnson-Laird (1983) proposed a theory of mental models in which he defined mental models as structural analogues of the real world, which are specific not generic representations.

Most of the research on mental models has focused on adults. Carey (1985a) presented a compelling case against the existence of any fundamental difference in the thinking of children and adults. She discussed studies that suggested that the only difference between children and adults is in domain specific knowledge. Therefore it is assumed that children use similar but perhaps less sophisticated mental models than adults.

A danger with much of the work in the mental models field is that the mechanisms proposed for knowledge storage and thinking draw heavily on comparisons with storage mechanisms and processes that could be implemented on computers. However the structure and function of the human brain, although not fully understood, is known to be significantly different in its nature and infinitely more complex than any computer that has been developed.

The variety of types of mental models is still an open question and no complete account has been given of the components of mental models. In addition, the possibilities of existence of other types of mental knowledge representation has not been ruled out. Therefore there was no possibility of basing the design of the modelling environment on a known type of mental representation. Even if these mechanisms were fully understood, it was not self evident that a modelling tool should be analogous to these representations. It would still be important to consider how the tool could facilitate communication of ideas and this would probably entail knowledge restructuring for different recipients.

There may be dangers in restricting people's range of expression by providing only one type of formalism. This presents a dilemma for the design and use of a modelling environment because the more different representation methods that are provided, the more complex the environment becomes for the learner to use and manipulate. In the future there may be ways of providing computerised help for learners in selecting a formalism but for this research it was recognised that the environment was only one of a range of tools within the teaching/learning repertory. The teacher would need to oversee its use alongside other tools including both computer-based and non computer-based systems.

The mental models theory has implications for the design of the modelling metaphor because the user would need to construct a mental model of the metaphor in order to make use of the environment to build a model. This mental model need not be a complete representation of the structure and function of the system but it must enable modellers to structure their knowledge in the modelling environment so that the models will behave appropriately. This suggested that the metaphor should be as easy to understand as possible without compromising its versatility in relation to children's modelling needs. Effort should be directed towards presenting the metaphor to the user in such a way that (s)he can develop an appropriate mental model.

3.5 How learners construct knowledge

The discussion so far in this chapter has focused on the constructivist approach as a theoretical basis for learning and teaching and has considered its philosophical underpinning as well as considering methods of representing knowledge. In this section theories about the processes that lead learners to construct knowledge are discussed.

3.5.1 Piaget's theory of how learners construct knowledge

Piaget (1978) suggested that:

> *"the most fruitful factors in the acquisition of understanding were the results of disturbances producing conflicting situations"* (p39).

Old cognitive structures develop into new ones in response to external experiences where the external phenomena are in conflict with the internal cognitive structure. This is described as cognitive conflict. The Piagetian view of learning, then, put learners in control and suggested that the provision of a rich and varied learning environment would enable learning to take place by the process of equilibration. But when does cognitive conflict lead to cognitive development? Piaget suggested that it does not always do so. Where does the revised conception come from? Piaget did not fully address these questions.

Piaget seemed to suggest that there is a natural tendency towards equilibration:

> *"the subject seeks to avoid incoherence and always tends therefore to certain forms of equilibrium"* (p48).

Piaget's ideas about learning have been very influential in education in the UK and, as discussed in Section 3.2, constructivism has some basis in Piagetian theory. However the constructivist approaches, advocated by the CLIS Project and the SPACE Project do not make use of cognitive conflict. Rather than determining children's ideas by setting up learning situations that challenge "misconceptions", both methods enable children to test their ideas and discuss them. This may result in ideas being modified or abandoned if children decide that this is necessary in the light of evidence.

Papert (1980) claimed that he applied Piaget's model of children as builders of their own intellectual structures to a consideration of the use of computer technology for learning. Papert himself recognised that his interpretation of Piaget's ideas was unorthodox. His proposals emphasised the importance of the surrounding culture on a child's development rather than ontogenetic factors. They bore some resemblance to those of Vygotsky, which are discussed in the next section, as well as to the constructivist approach outlined in Section 3.1. In "Mindstorms", Papert emphasised that in order to build their own intellectual structures, children use materials that they find around them and models and metaphors suggested by the surrounding culture. For example, children learn to speak by being within a language culture surrounded by people who speak. He suggested that the computer culture, which was just beginning, would provide a rich environment of materials, models and metaphors for children to use when constructing their knowledge. Papert suggested that the computer could concretise and personalise formal ideas. Papert developed the LOGO programming language to provide environments in which children could explore ideas and test hypotheses. Turtle geometry is one such microworld in which children can explore mathematics.

There was controversy over the benefits of learning to program in LOGO (e.g. Pea and Kurland, 1986). According to Papert this came from taking too narrow a view of the possible benefits. The main area of controversy was whether or not learning to program enhances general problem solving skills. This will be returned to later in Section 3.9.2. The focus of the current discussion is on whether or not learning theory can support the proposal of children's learning being enhanced by modelling and whether there are any messages for the design of appropriate tools. Piaget's theory that children learn by actively constructing knowledge does not conflict with the hypothesis that providing appropriate tools for expressing knowledge should enhance learning.

3.5.2 Vygotsky and intellectual development

Vygotsky's ideas differ from those of Piaget in that he focused on the importance of social and cultural influences on intellectual development rather than taking Piaget's view that the maximum rate of cognitive development is limited by ontogenetic factors. Vygotsky made some claims about the importance of tools which are particularly relevant to this discussion.

In "Thought and Language" (1986) Vygotsky distinguished two forms of learning which are responsible for concept formation. The first is a systematically organised learning in an educational setting, which is imposed on the child and develops so called "scientific concepts". The second type of concepts are spontaneous concepts which emerge from the child's own reflections on everyday experiences. Scientific concepts undergo substantial development that depends on the existing level of a child's general ability to comprehend concepts. This level of comprehension is connected with the development of spontaneous concepts. Vygotsky emphasised the importance of the child interacting with her/his peers and with adults. He defined the "zone of proximal development" (ZPD) as the distance between a child's actual development level and her/his level of potential development and stated that:

> *"the only "good learning" is that which is in advance of development."* (p86).

Vygotsky, here, provided a synthesis of the relationship between learning, teaching and development that will ring true to many teachers. He was acknowledging the importance of ontogenetic development as providing constraints on learning. He also recognised the importance of the child's own experience but he saw possibilities for the child's cognitive development to be accelerated by appropriate educational environments.

Vygotsky emphasised the importance of tools and signs in intellectual development. In "Mind and Society" (1978) he argued, from Marxist philosophy and particularly from the belief expressed by Engels, that human labour and tool use are the means by which man changes nature and in so doing transforms himself. Vygotsky extended this concept to suggest that:

> *"the sign acts as an instrument of psychological activity in a manner analogous to the role of a tool in labour."* (p52)

A sign, in this context, is an auxiliary external stimulus, e.g. a notched stick might be used in a primitive culture, or in a more advanced culture, language, writing or number systems would be signs. By reasoning in this way, Vygotsky saw intellectual progression as being closely linked with historical and cultural development. Vygotsky's emphasis on the importance of social and cultural influences in intellectual development is consistent with Papert's suggestion (Papert 1984) that the child learns computing by being immersed in a computer culture. Vygotsky distinguished between tools and signs by stating that:

> *"the tool's function is to serve as the conductor of human influence on the object of activity; it is therefore externally oriented; it must lead to changes in objects. The sign, on the other hand, changes nothing in the object of a psychological operation. It is a means of internal activity aimed at mastering oneself: the sign is internally oriented."* (p55)

It is the internalisation of sign systems which brings about transformations and forms the bridge between early and later forms of individual development. Vygotsky did not fully describe the actual process of internalisation but made clear that the sign is reconstructed during this process and that the external and internal forms of the sign are not identical. He also defined three stages in this process for mediation of memory:

1. in the pre-school child who is unable to use sign systems to improve performance
2. in the child who uses sign systems externally
3. in the adult who has internalised the sign system.

These sign systems could be any external auxiliary stimulus that a person might make use of in order to help her/him perform an intellectual function. In one of the experiments described by Vygotsky, coloured cards were used to assist memory. The use of diagrams and schematic representations could also be regarded as signs to aid thinking. Particular methods of processing information which computers employ could also be regarded as signs. Salomon (1988) suggested that:

> *"learners can internalise computers' intelligent tools and use them as cognitive ones."* (p 123)

Salomon here was using the term 'tool' where Vygotsky used sign. Salomon cited work by Hatano et al. (1977) which suggested that there are intermediate observable steps in the process of internalisation. Hatano et al. conducted an investigation in which ten expert abacus operators were given restrictions and distractions so that they had to make more use of mental operations. They stated that the abacus seemed to be a tool that is internalised to such a degree that many abacus masters can calculate even faster and more accurately without an abacus. Some move their fingers during mental calculations as if they were moving an abacus and most subjects said that they imagined arranged beads of an abacus when they heard a number. The results of the investigation by Hatano et al. supported the hypothesis that operators tend to internalise abacus operation through a transition stage wherein the mental operation is not completely independent from the motor system and abacus-simulating finger movement gives important support. As they progress the mental operation comes to involve only visual representation.

Perkins and Salomon (see Salomon (1988)) developed a theory of learning where learning and transfer can take either one of two routes or a combination. One route, termed the "low road" is characterised by much practice in a variety of situations leading to the near automatic mastery of the cognition skills. The "high road" on the other hand, is fast and accompanied by much "mindfulness" through which the individual deliberately extracts the essentials of the material and decontextualises it. Salomon defined "mindfulness" as the '*metacognitively guided, deliberate and focused employment of non-automatic mental operations in the service of performing some task*'. He went on to argue that the "high road" is a better approach to the use of tools and that learners should be encouraged to use the tools in a mindful manner.

Salomon's suggestion that *learners can internalise computers' intelligent tools and use* *them as cognitive ones* is probably an overstatement. The signs that Vygotsky mentions are those in frequent use, e.g. language and number systems and the work by Hatano et al. was based on regular abacus users. To design a completely new formalism that is likely to be internalised was too ambitious for this research but to seek to adopt and extend an existing formalism in such a way that it may become easier to use and perhaps internalise was a possibility.

Vygotsky's work on intellectual development, which is outlined here, contributed in several ways to this project. First, it supported the idea that using a computer based modelling environment could encourage intellectual development by acting as an instrument of intellectual activity. Secondly it suggested that it would be fruitful to look for an existing formalism that could be developed so that it might be able to be internalised. Possible candidates for such a formalism, in the context of qualitative modelling, were natural language or some form of logic. Logic is explored in the next section. Thirdly, the concept of the zone of proximal development suggested that children should be encouraged to work at levels of intellectual functioning beyond their current levels. This contrasts with the Piagetian developmental view of learning that has influenced pedagogical styles in the UK.

Piaget's view of learning as an active process and the subsequent development of constructivist approaches to learning were not in conflict with Vygotsky's ideas. The latter would however influence the type of teacher intervention and place greater emphasis on social interaction. The application of Vygotskyian theory of 'learning in advance of development' to constructivism would encourage teachers to provide "scientific explanations" even though the children might not fully grasp them at the time. This 'learning in advance of development' would also depend on enabling social interaction which is discussed in Section 3.8.

3.6 Candidates for a qualitative modelling formalism

Qualitative modelling involves some form of reasoning so the nature of reasoning and how reasoning skills develop were explored in the search for a possible formalism for qualitative modelling. This work also identified the range of different types of reasoning that the environment should support. There is some controversy over whether human reasoning is based on logic or on using mental models. Arguments from both sides of this divide were identified and are outlined here.

3.6.1 Formal logic

Formal logic is concerned with rules for drawing conclusions from evidence with certainty. It includes predicate and modal logic and is described in textbooks on logic.

3.6.2 Reasoning

Baron (1988) described a study by Perkins (1985) who looked for evidence of fallacies in actual reasoning by high school students, university students and other adults. Perkins then asked two critics to criticise them in their own words. Then researchers classified the criticisms. Most criticisms fell into the broad group of "sparse situation modelling" - the original reasoning did not have an elaborate enough model of the situation. These errors could also be described as failure to search for evidence against initial possibilities. They were not errors in logic as such and they were not classical fallacies. Baron argued that most of the so-called fallacies, when we notice them in people's real life reasoning, are (at worst) cases of the overweighting of evidence rather than of the use of irrelevant evidence.

Donaldson (1976) suggested that there are two kinds of language comprehension. Ordinary comprehension tries to arrive at the meaning a speaker or writer intends. This comprehension process uses all the information available including general knowledge and knowledge of the speaker. The other kind of comprehension has as its purpose to discover the meaning of a sentence - not what the speaker means by the sentence but what the sentence itself means. This kind of comprehension is common in legal work and is also important in communicating whether in writing or orally. Braine and Rumain (1983) referred to this type of comprehension as "analytic" and commented that it is a relatively high level verbal skill in which there are large differences among adults. They suggested that formal reasoning from premises demands analytic comprehension of the premises. However a subject may use ordinary comprehension processes and children can be expected to use ordinary comprehension processes.

In the attempt to explore what was meant by 'reasoning' it became clear that the controversy over the relationship between logic and reasoning had prevented the establishment of a universally accepted definition. This controversy is revisited in Section 3.6.6 where the methods that people use to reason are discussed but first the range of different types of reasoning that have been identified are considered.

3.6.3 Types of reasoning

The types of reasoning that can be used are explored here because a qualitative modelling environment should enable the expression of at least some of these. Three types of reasoning are generally recognised: deductive, inductive and abductive but in addition there is now recognition of "practical logical reasoning". The nature of inductive and deductive reasoning is well known and is discussed in basic texts.

Abduction asks the question "How can I conclude that something has occurred", i.e. it looks for observable evidence. Abduction is therefore important in generating hypotheses and in giving explanations, e.g.:

How can I conclude that it has rained?

evidence: the pavement is wet.

Practical logical reasoning is a phenomenon that has been given more prominence recently. Nickerson (1986) stated that there seemed to be considerable agreement that students sometimes manage to complete many years of formal schooling without acquiring the ability to reason very effectively about complex or perhaps even relatively simple problems.

Braine and Rumain (1983) distinguished between formal logical reasoning and practical logical reasoning. Formal logical reasoning uses explicit premises and is concerned with what statements follow from the premises. Practical logical reasoning occurs in everyday-life situations.

Braine and Rumain listed differences between these two types of reasoning:

- For formal reasoning the starting information is laid out in premises whereas in practical reasoning the starting information may come from general knowledge, from specific facts that have been discovered, or from verbal communications which have been understood through ordinary comprehension processes.
- Formal reasoning demands analytical comprehension whereas practical reasoning does not.
- Formal reasoning demands a compartmentalisation of information. The reasoner must separate the information gained from the premises and use only that information.

There are similarities between formal and practical reasoning in the inference-making process itself. Practical reasoning includes inferences based on plausibility but some of it is logical, e.g. if you have a friend in London who is coming to visit and has not yet made up her mind whether to drive or come by train. She says that she will phone by six o'clock if she is coming by train so that you can be at the station to meet her. When she has not phoned by six you assume, by a process of logical reasoning, that she is driving. Braine and Rumain concluded that formal and practical reasoning share a common logic. In all forms of reasoning the inference process, which a person employs to reason from starting points to conclusions, is the same although in everyday reasoning the starting points may come from various sources.

The recognition that practical reasoning may be different from formal logical reasoning led to a movement towards defining a new form of logic. This 'informal logic' is examined in the next section.

3.6.4 Informal logic

The informal logic tradition has developed from an interest in how people reason in real situations and attempts to provide a generalised model for everyday reasoning. One approach was that of Toulmin (1958) who claimed that the form of reasoning used in legal proceedings was the correct model for everyday reasoning. Toulmin tried to account for the structure of all arguments by suggesting that they contain the following structure:

```
Datum (D)---------------------------------------> Qualifier (Q), Claim (C)
                  |                               |
                Warrant (W)          Rebuttal (R)
                  |
                Backing (B)
```

Fisher (1990, pp17-18) has applied this to reasoning where a doctor is advising a patient:

Doctor:	*Its an upper respiratory infection (D), so a couple of days off work and a four day course of penicillin will presumably (Q) get you back to normal health quick enough.*
Patient:	*Are you sure that won't do more harm than good? I'm allergic to penicillin. (R)*
Doctor:	*Are you indeed? In that case, I take back what I said. It's tetracycline not penicillin for you.*

The diagram is:

```
Patient has straight forward URI(D)-----------------------> presumably (Q), Patient needs penicillin (C)
                                                  |                           |
Straight forward URI's need penicillin treatment (W)          unless allergic to penicillin (R)
                                                  |
                                    Clinical experience (B)
```

Fisher stated that Toulmin's approach appears to be deeply flawed, as it stands, because researchers who have tried to use his approach on other examples have had great difficulty in distinguishing data from backing, etc.

A central concern of informal logic is argument analysis and there is an "argumentation model" of informal logic. This is a broader framework than formal logic and looks at reasoning in context which is often a dialogue. The dialogue is analysed as propositional arguments where appropriate. In addition, "suppositional reasoning" is used. During the dialogue people say things like "What if we try this?"

Collins and Michalski (1989) extended logic by proposing a number of new types of syllogism to account for what they call "plausible reasoning". Plausible reasoning is equivalent to what Toulmin would call reasoning with quantifiers. They have explained such reasoning in the context of dialogues where people often make plausible inferences about facts of which they are unsure. Here is an example:

Q:	*Is the Chaco cattle country? I know the cattle country is down there (in Argentina).*
R:	*I think it's more sheep country. It's like western Texas, so in some senses I guess its cattle country. (pp5-6)*

Here R brings two pieces of evidence to bear on the question. The first is that he recalls (without much confidence) that the Chaco is sheep country, and he infers from this (implicitly) that the Chaco is probably not cattle country. The second is that he recalls (confidently) that the Chaco is like western Texas, which he knows to be cattle country. This provides evidence on the other side.

The way in which inference is made follows a pattern in each case and in the first case the syllogism can be laid out as:

- Sheep are found in the Chaco (uncertain)
- Sheep and cattle are both kinds of livestock (certain, typical kinds, frequent kinds)
- Sheep are dissimilar from cattle in the vegetation they are associated with (certain)
- The vegetation of a place is related to the livestock in the place (moderate dependence of livestock on vegetation, strong dependence of vegetation on livestock, (certain)
- So the livestock of the Chaco does not include cattle (weak).

Each statement takes a particular form and has the following parameters:

- its certainty
- when the statement is about a type of something, a degree of typicality and a frequency
- when the statement is about a dependency relationship, the strength of dependency in both directions.

The strength of the inference depends on the parameters of the various statements.

Collins and Michalski discussed other general patterns of inference that are used in plausible reasoning. One common pattern is a "lack of knowledge inference", in which one makes an inference from ones lack of knowledge, e.g. if a goose could quack, I probably would know it, so probably a goose can't quack.

Baron (1988) suggested that inferences are only part of the story; reasoning involves both search and inferences.

3.6.5 How people reason

The question as to whether people reason according to the rules of logic is still a controversial one. In this section theories about how people reason will be examined from both sides of this divide.

3.6.5.1 Reasoning using logic

If people reason using logic, they cannot rely solely on formal logic for two reasons. First, formal logic enables inferences to be made only with information given in the premises whereas in order to deal with everyday situations people need to use whatever relevant information they have. Secondly people are able to reason with uncertainty whereas formal logic has no such mechanism.

Braine and Rumain (1983) suggested that people possess inference schema which are developed at a fairly early age. They elaborated a set of such schema for propositional logic and reported empirical studies which support the existence of these schema in adult subjects.

Braine and O'Brien (1991) contended that how people understand "if" is crucial to an adequate description of human cognition because "if" is psychologically richer than the other connectives owing to its association with supposition.

3.6.5.2 Mental models and reasoning

In contrast to the approach based on logic, Johnson-Laird and Byrne (1991) proposed that people reason by manipulating mental models in working memory and that there is no involvement of logical schema. According to this theory, errors occur because people fail to consider all possible models of the premises.

The mental models theory easily accounted for reasoning about spatially oriented objects and for categorical reasoning where structures such as Venn diagrams can be envisaged.

Where the two theories disagree is over the proposal that all reasoning is based on mental models and that any role for inference schema is specifically excluded. Braine and O'Brien's theory allows for the use of mental models for understanding some conditionals but suggests that others need not involve mental models. The example they provide is based on a concealed number and the conditional statement *if the number ends in zero then it is divisible by 5.* They argue that there is no need for a model to be used in reasoning that this statement is true and that there is no useful model for this purpose.

The disagreement between these two schools of thought then hinges on whether all mental processing involves mental models.

3.6.6 Implications for the design of a modelling environment

In this section a review of logic and reasoning has been presented because qualitative modelling will involve some form of reasoning and the modelling environment needs to facilitate appropriate use of some form of logic and/or reasoning. The controversy over the mental representations used in reasoning was relevant in that if people always use mental models for reasoning then using a modelling environment based on rules would entail a complete restructuring from their mental representation and this might not facilitate their expression. An alternative approach would be to use verbal or pictorial descriptions of the situation and its possible consequences. There is probably a great deal of scope here for modelling environments but it would not be easy to find a generaliseable representation that would be meaningful to most people and could be run. The rule based approach had an advantage in that it might enable learners to communicate their ideas since communication of even a fairly simple piece of reasoning would usually make use of rules with logical connectives. The use of rules could also help learners to check their reasoning.

In summary then, even if people always used mental models for reasoning rather than rules, the use of a modelling environment that necessitated the reformulation of reasoning from mental models into rules could be beneficial in helping learners to communicate and check their reasoning. The nature of the logic that people use in reasoning is still a subject of research. Therefore one approach to providing facilities in a qualitative modelling environment would be to enable as much flexibility as possible so that people could use a range of types of logic and reasoning.

3.7 Development of reasoning skills

Piaget regarded the development of logical structures as of key importance in cognitive development. Piaget and Inhelder (1969) argued that limitations in operational thought place limits on the child's capability to build theories. Piaget claimed that young children have no comprehension of causality but Carey (1985b), as discussed in Section 3.3, reported evidence which suggested, contrary to Piaget's view, that the pre-school child appreciates mechanical causality.

Braine and Rumain (1983) reviewed the evidence from empirical work and concluded that some basic logical competence is available to children early, at least by around school-entering age. This competence comprises a repertoire of inferences. In propositional reasoning it includes modus ponens. Braine and Rumain suggested that this early logical competence is acquired as part of learning the language. This suggestion is not based on empirical evidence but on the consideration that the inferences that comprise the early competence appeared to be closely tied to the meanings of words like if, or, all, may, etc. They claimed that it was hard to see how one could understand the words without knowing the inferences.

Braine and Rumain also quoted evidence for extensive inadequacies of comprehension at all ages, e.g. children often fail to attend to which clause the word "if" or "because" is attached and hence do not use this as a clue to which is cause and which effect.

3.7.1 Implications for the design of a modelling environment

Evidence on the development of reasoning skills contained two important messages for the design of a modelling environment:

1 No children within the school age range are likely to be precluded, by their lack of logical structures, from using an environment that requires some reasoning ability. This follows from the studies of Carey and others, which she cited, and contradicts the Piagetian view.

2 There are some types of reasoning that children and some adults find difficult so that an environment that focuses on reasoning could help to develop these abilities. The evidence for the development of specific reasoning skills, reviewed by Braine and Rumain (1983), is incomplete. Therefore it was not possible to be very precise about children's development of all of these skills. Such a task was not essential for this research since the modelling environment was not intended to provide for the learning of specific reasoning skills. This point is therefore highlighting a possible additional benefit of a modelling environment based on logical reasoning.

3.8 Group work

The importance of social interaction for learning was recognised by both Piaget and Vygotsky. In English primary schools it has been considered "good practice", particularly since the 1967 Plowden Report, for children to work together cooperatively or collaboratively in groups. This aspect of classroom practice has been attributed largely to the influence of Piaget's idea of learners as active builders of their own intellectual structures where the teacher is seen as a facilitator rather than an instructor. Peer interaction was also regarded as beneficial for learning. In this section the theoretical basis for the view that social interaction is important in learning is reviewed and evidence from empirical studies is outlined.

3.8.1 Piaget's views on group work

Piaget claimed that old cognitive structures develop into new ones in response to external problems that is where the external phenomena are in conflict with the internal cognitive structure. Piaget suggested that one of the most important factors in bringing about such cognitive conflict is interaction within a peer group. Piaget (1978) referred to both cognitive conflicts in the intra-individual plane and sociocognitive conflicts in the inter-individual plane. He stated that the interchange of thoughts with others in interactive contexts follows the same principles of equilibration as does conflict that arises through solitary reflection.

3.8.2 Vygotsky's views on group work

Vygotsky (1978) emphasised the importance of the child interacting with her/his peers and with adults. He stressed the importance of the cooperative nature of learning:

> *"We propose that an essential feature of learning is that it creates the zone of proximal development; that is, learning awakens a variety of developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with peers. Once these processes are internalised they become part of the child's developmental achievement."* (p87)

Both Piaget and Vygotsky then, asserted the importance of social interaction in cognitive development. Whereas Piaget emphasised the value of peer interaction as one way of bringing about cognitive conflict hence leading to cognitive restructuring, Vygotsky saw a key role for interaction both with peers and with adults.

3.8.3 Situated learning

Suchman (1987) proposed that since actions are always situated in particular social and physical circumstances the situation is crucial to interpretation of actions. She argued that the very obviousness of this fact contributes to the ways in which it has been overlooked in cognitive science. Suchman proposed that the aim of research should be to explore the relation of knowledge and action to the particular circumstances in which knowing and action occur rather than to produce formal models of knowledge and action. This approach, according to Suchman, requires three fundamental changes in research procedure. First there is a need for a change in perspective such that the contingence of action on a complex world of objects artefacts and other actors, located in space and time, is no longer treated as an extraneous problem with which the individual actor must contend. Rather, this contingence is seen as the essential resource that makes knowledge possible and gives action sense. The second change is a renewed commitment to grounding theories of action in empirical evidence. Finally this approach assumes that the coherence of action is not adequately explained by either preconceived cognitive schema or institutionalised social norms. Rather, the organisation of situated action is an emergent property of moment by moment interactions between actors and between actors and the environment of their action.

Suchman's approach has a very different emphasis from that of much of the cognitive science work, discussed earlier in this chapter, including that of proponents of the mental models school of thought. It is, however, not inconsistent with the important status of social interaction in learning ascribed by both Piaget and Vygotsky.

Suchman's particular interest in situated action focused on the design of interactive machines but other workers, notably Lave and Wenger (1991), have considered situated action in relation to the whole learning environment. Lave and Wenger proposed that "learning is an integral part of generative social practice in the lived-in world." They focused on a process which they referred to as *"legitimate peripheral participation"* which concerns the process by which newcomers become part of a community of practice. Learning is viewed as an integral part of social practice as opposed to a process by which a learner internalises knowledge. However, although Lave and Wenger presented a compelling case for situated learning and described a clear theoretical framework, they only began to discuss what kinds of social engagement provide the proper context for learning to take place. They emphasised that legitimate peripheral participation is a way of understanding learning not a pedagogical strategy. Their examples came from apprenticeships. The school situation was left for later analysis.

Lave and Wenger discussed their theory in relation to Vygotsky's ideas which also emphasised the importance of social context. They commented that Vygotsky's concept of the zone of proximal development has received vastly different interpretations. Some interpretations emphasise the importance of pedagogical approaches that provide support for the initial performance of tasks to be performed later without assistance. The social character of learning, in these interpretations, is limited to "*a small aura of socialness that provides input for the process of internalisation viewed as individualistic acquisition of the culture given*". Lave and Wenger referred to contemporary developments in the traditions of Soviet psychology, in which Vygotsky's work figures prominently, which focus on processes of social transformation and are closer to the perspective of Lave and Wenger.

In the contexts of the apprenticeships, which Lave and Wenger analysed, legitimate peripheral participation provided a very fruitful way of learning and it may be regarded as a better way of learning than that provided by the typical school situation where learning has been decontextualised. Much effort in schools is directed towards providing relevance and relating teaching to children's own experiences. The notion of situated learning presented by Lave and Wenger provides an analytical approach to learning which they believe could fruitfully be applied to schooling although they comment that such an analysis would be a major task. The implications for this research are to re-emphasise the importance of the social context as an essential part of learning. Classroom situations cannot provide for situated learning in the same way as an apprenticeship but there are opportunities for legitimate peripheral participation where the teacher or more able pupils are performing key parts of the task.

3.8.4 Empirical studies of group work

There is considerable empirical evidence to support the view that social interaction can promote cognitive development and the studies were mostly based on Piaget's theory of cognitive conflicts. Doise et al. (1975) showed that children working in pairs generated sociocognitive conflicts that enabled them to solve problems at a more advanced level than children working individually on the same problems. Perret-Clermont (1980) reported that peer group interaction promoted cognitive development in mixed ability groups for both the more able and the less able members of the group. Perret-Clermont accounted for these findings in terms of the child's active restructuring:

> *"The importance of social interaction is not only for the opportunity of imitating another child, and thereby the possibility of conflict with one's own way of doing things, but also and more often, the opportunity to elaborate actions with another child and thus to coordinate centrations even though these may initially be different."* (p 176).

Most of the earlier studies of social interaction focused on the transition from the Piagetian preoperational stage to the concrete operational but more recently Dimant and Bearison (1991) studied peer interactions during the transition from concrete operational to formal operational. They found that individual cognitive gains were accounted for by the *quality* of subjects' social interactions.

Although group work was considered to be the norm in primary schools Alexander (1992) reported findings from the "Leeds" study into primary education that showed that many teachers had problems implementing "good primary practice" particularly with regard to group work. The "Leeds" study was an independent evaluation of Leeds City Council's Primary Needs Programme that was a major initiative to improve primary education by providing more resources and promoting "good primary practice". Alexander reported that many teachers adopted the group work approach as a method of classroom organisation without engaging with deeper issues about what purposes such practice might serve. They encountered problems including:

- reconciling group work with their simultaneous sense of obligation to monitor, diagnose, assess and interact at the level of the individual child. A common solution was to neglect those children working on curriculum areas perceived to be relatively less important.
- planning the work where children were engaged in a variety of different tasks.

Galton and Williamson (1992) reported a number of studies that suggest that, although children did indeed sit in groups, oral exchanges between pupils were much rarer than would be expected. They suggested that teachers had adopted the group work model primarily to cope with mixed ability teaching rather than for ideological reasons and that there were a number of difficulties in organising effective group work. The Oracle study (Galton and Williamson 1992) led to the identification of strategies for effective group work. It was not possible to elucidate a simple set of guidelines but a number of important principles were outlined (p121):

- The value that the teacher places on collaboration must be clearly communicated to the pupils.
- Children need to be taught how to collaborate.
- It is best to begin with small practical activities where there is a specific solution to the problem rather than more open-ended problem solving.
- Where evaluative teacher feedback about children's mistakes is required it should be delivered to the class in general rather than to a group in particular in order to minimise its discouraging effect.
- Pupils need to feel that the teacher understands what it feels like to work in groups so that they will not, for example, be accused of time wasting when they are in fact discussing.

The evidence therefore suggested that social interaction could support cognitive development but that this might not be fully exploited in schools because there was a need for better guidance for teachers in managing effective group work. Computers could provide a focus for group work so the more limited evidence of group work with computers was examined and is discussed in the next section.

3.8.5 Group work and computers

A computer adds a new dimension to group work in that students are not only interacting with each other but also with the computer. One finding of the "Information technology and the whole curriculum 9-14" project, reported by Eraut and Hoyles (1988), was that while pupils frequently engaged with computers in groups the purpose is usually to maximise access to a limited number of terminals. Hence the potential of group work was rarely exploited and collaborative learning in such groups happens more by chance than design.

There was some evidence that collaborative working in groups could enhance learning but it suggested that there are complex issues involved in successful peer interaction. Noreen Webb (1984) reported the results of a study of computer programming in small groups that showed that oral interactions in the group seemed to influence learning of basic commands and syntax but did not affect interpreting and generating graphics programs. Webb explains this result in terms of the difference in the learning medium. The strategies or approaches and results are clearly seen by everyone because they appear on the screen in a standardised fashion. Therefore students can learn from what other group members do as well as from what they say. Thus the group processes influencing the learning of how to interpret and generate graphics programs may have been predominantly nonverbal.

The group work with computers project (Hoyles et al., 1994) identified different styles of group organisation - the ways in which the groups organised themselves in relation to the tasks and resources and different patterns of interaction based on the relative influence of individuals on different aspects of the task. They found that both group productivity and effectiveness in terms of learning of individual pupils were most often associated with a collaborative style of organisation where the group shared out task sub-components and came together to discuss their results. Individual learning in mathematics was related to the extent to which pupils were able to formalise their ideas and discuss them with their peers. In the case studies described by Hoyles et al. there was little teacher intervention; groups of pupils were given a great deal of autonomy and organised themselves.

The optimum group size probably varies depending on the task, the user interface of the software and the children's experiences of group work. Trowbridge (1987) found that pairs are the most effective grouping for producing high levels of interaction and for developing improved problem solving heuristics. In the case studies reported by Hoyles et al. pupils were in groups of six but organised themselves into sub-groups of two or three.

3.8.6 Implications for the design of a modelling environment

In summary to this discussion about social interaction and learning there was considerable theoretical support and empirical confirmation for the importance of social interaction for promoting cognitive development. Existing primary practice, although it superficially reflected the importance of social interaction, did not always achieve effective group work, according to studies reported by Galton and Williamson. In order to enable appropriate interactions teachers need to adopt a suitable strategy for promoting effective group work. Use of this strategy would be important in defining tasks using a computer as with any tasks.

The modelling environment was intended to facilitate group work but was not designed solely for group work because teachers would also be likely to want to make it available for individual project work. The design features that would be particularly important for facilitating group interaction were those concerned with the screen presentation of the modelling environment and these are discussed in Chapter 4 (Section 4.4) and Chapter 5 (Section 5.3).

3.9 Empirical evidence of learning by modelling

In this section the empirical studies in which students were engaged in modelling activities both with and without computers are reviewed. These studies were examined in order to assess the evidence of the kinds of learning that might be taking place during modelling activities.

3.9.1 Modelling without computers

Osborne and Gilbert (1980) gave one of the very few accounts of the use of models in science teaching and the problems and difficulties associated with their use. They also presented a little empirical evidence from a small study. Their discussion pre-dated the availability of computer modelling environments in schools but described the extensive use that is made of diagrammatic and verbal representations, scale models, mathematical models and analogue models in science teaching. Osborne and Gilbert commented that in such cases the use of models can lead to confusion rather than illumination. They listed some of the general difficulties which students met in relation to models as:

- they lack awareness of the intellectual boundary between the model, the source of the model and the reality whose behaviour the model is attempting to explain.
- they tend to persist in the use of the most rudimentary model, even though they have been introduced to a range of models of the same class in a given topic area.
- they find difficulty in applying given models in different contexts.
- they find problems in relating models of different classes within the same topic area.

Osborne and Gilbert's work related to situations where students were shown or given models which they were expected to assimilate and use rather than models which students could interact with and build. This has only become possible for many types of models with the availability of computer based modelling environments.

In a survey Webb et al. (1994) found a large number of accounts in the School Science Review of teachers using models and modelling in their teaching but very few accounts of studies where children's understanding of models or the learning that accompanied the use of models was investigated.

Mathematics is another area of the curriculum where the importance of modelling has been emphasised as an approach to problem solving, Mason (1988). This approach has been slow to become established in schools. Burkhardt (1984) reported a number of difficulties in introducing modelling into school mathematics teaching and there have been few detailed empirical studies of children modelling. One exception to this is work with LOGO, which is discussed in the next section.

3.9.2 LOGO

Papert developed the LOGO programming language to provide environments in which children could explore ideas and test hypotheses. LOGO is probably the most extensively used computer based modelling environment for children to construct their own models. Various claims have been made for the beneficial effects of children using LOGO on the development of cognitive skills and in particular, problem solving skills. Investigations have produced conflicting and inconclusive results. A number of studies were able to show evidence for positive effects of experience of programming in LOGO on higher thinking skills, e.g. Many et al.. (1988), Cathcart (1990), Clements (1986). The results of some other studies, reviewed by Pea and Kurland (1986), did not support this position. For example, Pea, Kurland and Hawkins (1986) reported a study of the effects of learning to program in LOGO on planning abilities of children aged 8-12. The LOGO group had about 30 hours using LOGO over the school year but no significant differences in the development of planning abilities were found, on a range of tests, between the LOGO group and the control group. Pea and Kurland (1986) provided a review of empirical studies of children using LOGO which revealed that there were many claims for the benefits of learning to program in LOGO on a variety of higher order thinking skills but that there was no clear evidence to substantiate the claims.

The fact that this debate about the effects of learning with LOGO on the development of thinking skills was still continuing, with little general agreement, 13 years after Papert wrote "Mindstorms" encouraging the use of LOGO as a learning environment, may be explained by different perceptions of the value and place of LOGO in education, differences in pedagogical style and by the limited availability of computer facilities in most schools. LOGO was originally presented as an environment for open-ended exploratory learning. Papert's stated purpose in developing LOGO was to make information technology available as a tool for learners in order to provide a richer learning environment. In "Mindstorms" (1980) Papert encouraged teachers to promote such exploration of mathematics rather than "teaching" children to program. Papert did not support short-term studies of the cognitive effects of programming in LOGO such as that by Pea, Kurland and Hawkins.

Papert (1984) stated:

> *"A literature is beginning on 'the effect' of 'the computer' on 'cognitive development,' or on 'learning mathematics,' or on 'schools,' or on 'the classroom.' Such questions are totally meaningless.*
>
> *If programming does influence thinking, this influence must not be conceptualised as a direct consequence of learning to program. The kind of effect I have in mind is something more indirect. Fluency in programming provides an opportunity for teachers to teach in new ways and for students to learn in new ways."*

The studies by Many et al., Cathcart and Pea, Kurland and Hawkins laid stress on instruction in LOGO programming and on children solving simple problems with which they were presented. It was only towards the ends of the investigations that they tackled open-ended problems of their choosing. Therefore the students were not immersed in the computer culture and being enabled to pursue their own explorations in the way envisaged by Papert.

Pea and Kurland commented that an important limitation of many studies, including their own, was that they had looked at effects on high-level thinking skills, expected to emerge only at the higher levels in their account of programming skill, whereas the levels of programming attained by the students in these studies were low because they did only six weeks to a year or so of programming.

Most of the research into the benefits of learning LOGO was focused on the enhancement of general problem solving and cognitive skills. The evidence on this issue was inconclusive but the failure to provide convincing evidence could be explained by the short-term nature of the studies. An important issue in this debate was the increasing evidence that such skills may be context specific (Carey (1985), Keil (1986)). This suggested that using LOGO could not be justified purely on the claim that learning to program developed general cognitive skills. The turtle microworld of LOGO was actually designed to enable pupils to explore and develop their understanding of mathematics so this was a more important justification. Classroom use of LOGO in the UK has focused on this approach, e.g. Blythe and Noss (1983) and

Mathematics in the National Curriculum, Department of Education and Science and the Welsh Office (1991). Harel and Papert (1990) provided evidence for greater mastery of both LOGO and fractions as well as improved metacognitive skills by students involved in developing instructional software using LOGO.

Another important aspect of the taking up of LOGO as a learning tool was the style of learning which it is intended to foster. Children could be given control of their own learning. Burns and Hagerman (1989) reported a study of 8-9 year-olds programming in LOGO which provided evidence that experience with LOGO could lead to changes in specific measures concerning children's ideas of themselves as learners. They proposed that using LOGO could influence the child's view of self towards increased autonomy and intrinsic motivation in problem solving.

Empirical evidence from work with LOGO, then, was inconclusive. It was not yet proven whether or not using LOGO enhanced pupils' cognitive skills but the evidence for the context-specific nature of such skills called into question whether learning to program should be an educational priority. There was little to justify the use of any modelling environment purely on the grounds that it would develop general cognitive skills. The environment would need to be used in specific curriculum contexts. The use of LOGO microworlds to explore mathematics was not in conflict with evidence for the context specific nature of learning and there was some evidence for enhanced learning of mathematics by using LOGO.

Evidence for the use of LOGO promoting positive changes in children's views of themselves as learners was important. LOGO was an environment in which learners could come to perceive correcting their own errors as an important part of learning rather than an indication of failure and this could also be true of any modelling environment.

The work with LOGO left some confusion about how it may be integrated into the classroom environment and what are the pedagogical implications. Papert (1980) promoted an exploratory approach to mathematics using LOGO but did not give any clear pedagogical guidelines. Harel and Papert, in their investigation, did provide instruction in LOGO programming, as a means to an end rather than an end in itself, before students went on to develop programs based on problems that they themselves had set. Blythe and Noss discussed an approach based on teacher "interjection" as opposed to intervention. They commented that the latter implied a take-over by the teacher and a stifling of the children's ideas whereas interjection involved providing help, encouragement or suggestions where the teacher judged that this was necessary. Generally the teacher would allow students to solve their own problems but where (s)he judged that repeated failure was demotivating or inhibiting to learning (s)he would interject. The question of appropriate pedagogical style also needed to be addressed in relation to a qualitative modelling environment. The possibilities envisaged by Papert were at their early stages as computers were only just beginning to become available in schools in sufficient numbers.

The inconclusive nature of the results of empirical studies of the effects of using LOGO on children's learning highlighted the difficulties of such endeavours and also applied to the evaluation of the modelling environment. There is a need, as stated by Pea and Kurland, to undertake empirical research into the cognitive effects of using computers but it is important not to take too narrow a view of the role of computers. They are part of a whole learning environment which should be rich and varied in order to cater for the needs of the whole range of learners in the class.

3.9.3 Systems dynamic modelling

During the design phase of this project there was little information available to inform the design of the modelling environment from empirical studies of children undertaking systems dynamic modelling. The small scale trials, discussed in Chapter 2 (Section 2.4.1) (Webb, 1988 and Hassell, 1987), identified some of the strengths and weaknesses of STELLA, for use by students, but did not investigate the extent to which children were learning while modelling. Two other studies were reported during the evaluation phase of this project. Mandinach (1989) reported results from the Systems Thinking and Curriculum Innovation (STACI) project which used tools, such as STELLA, in secondary schools with students aged 13-18. STELLA was used to teach content-specific knowledge in science subjects and on a course on war and revolution. The teachers used models, illustrated them on the computer and integrated them into their classes at various degrees of complexity. In some cases the students interacted with models that were provided but in others they built models themselves. Their results indicated that the use of the modelling environment to build and explore models enabled students to acquire knowledge of systems concepts and apply them to scientific problems at varying levels of complexity and sophistication. Brna (1990) reported studies with the domain specific object-oriented modelling environments, DYNLAB and ELAB with 16-17 year-old students in physics classes. These environments proved useful for exploring concepts in Newtonian mechanics. The study suggested that it is practical to require students to build and run models. The researchers were able to identify students' misconceptions but the study did not go far enough to elucidate whether or not the experience of modelling enhanced their learning of the physics concepts.

The study by Mandinach included some students aged 13 who built very simple models but most of the students in these studies were 16-18. This supported the view of Webb (1988) and Hassell (1987) that the systems approach is more suitable for these older students.

3.9.4 PROLOG

The nature of PROLOG was discussed in Chapter 2 (Section 2.7.1) and several studies of the use of PROLOG with children were discussed. These studies highlighted the major limitations of PROLOG as a modelling environment, i.e. its complex syntax and lack of graphical facilities.

A further study by Scherz et al. (1990) revealed possible problems that could pertain to the use of other qualitative modelling environments and hence had implications for the design in this project. Scherz et al. reported that PROLOG has been taught to Israeli high school students aged 14-16. They chose PROLOG owing to its declarative nature which makes it suitable for the formalisation of subject matter in different areas. They reported a number of mistakes and misconceptions in four conceptual categories; personification, conservation, concretisation and preconception. Personification was a result of the similarity of PROLOG to natural language. They claimed that *"when PROLOG clauses look like English sentences students expect the computer to understand and to reason"*. This finding was significant in the design of a qualitative modelling environment in that although natural language gives a great deal of flexibility it may give certain messages to the children or perhaps support the misconception that computers are intelligent.

This study suggested that care would need to be taken in ensuring that learners understood the nature of the formalism used by the modelling environment and did not confuse it with natural language. It also suggested that learners would need help in structuring rules and that the provision of variables in a way that young learners could make use of would be particularly difficult to achieve.

3.9.5 Expert Systems

Bignold (1986), McCarthy (1986) and Davies (1986) conducted school-based trials with the expert system shell, Xi, that was designed for business use. They suggested that the process of building an expert system as an aid to learning, merits further research. However they all encountered a number of difficulties in using Xi for this purpose and their studies did not clarify how building an expert system could contribute to children's learning.

Galpin (1989) conducted a project in English primary schools with children aged 8-11 using simple expert system shells. He reported that the teachers believed that the pupils had gained positive benefits from the work and that some children appeared to benefit more than others. The extent to which children benefited from constructing expert systems did not appear to be related to their levels of attainment in other areas although these judgements were made purely from teacher assessments rather than any specific measures of attainment. After much discussion the teachers and researchers in benefited from constructing expert systems was related to the child's stage of cognitive development. They used Piagetian terms to describe such development and again their beliefs were based on judgements made as a result of observation. They concluded that children who had not progressed from performing entirely at the Piagetian concrete operational stage of thinking were likely to find the analysis of thought processes, which is necessary to create a model, beyond their capabilities. It was those children who were able to transfer to abstract modes of thought on occasions, or those who were ready to make such a transfer who had most success. The review of learning theory presented in this thesis (see Section 3.2) does not support the Piagetian stage model of development invoked in this study. Galpin's study showed that some children in some circumstances benefited from constructing expert systems but others did not and it was suggested that this was related to cognitive ability. The Piagetian stage model of development was not essential for explaining these results and other factors such as the context of the work and children's own prior experience may have been important. The teachers' judgement of the reasons for this difference was based on a range of observations of the children and it is not possible from the report to identify significant factors affecting this difference. The possibility that some children might benefit more from qualitative modelling than others was considered in the classroom evaluation which is discussed in Chapter 8.

Wideman and Owston (1988) reported a study where grade 7 students (aged 12-13) used an expert system shell to develop classification systems for living organisms. A typical assignment for a group of students was to produce a classification system for insects which would enable the classification of six species from six different orders at the order, family and species level. Students first created a chart and then constructed their systems using textual rules. Students were given help when they needed it. Wideman and Owston concluded that:

> *"the development of simple rule based expert systems can provide a valuable educational experience at a surprisingly early age, as long as the activity is properly structured and sufficiently supported. The groups were able to complete tasks of greater cognitive complexity than is typically demanded of*

> *them by the curricula for their age level and they did so with a good degree of enthusiasm.*
>
> *The externalisation of reasoning demanded by the knowledge base development task forced them to employ rigorous and systematic reasoning in order to succeed."* (p92).

Both of the empirical studies of the use of expert systems described above suggested that students could make use of expert system shells. Wideman and Owston's investigation was with older students but with more complex software and with more cognitively demanding assignments. The use of a simpler expert system shell and simpler assignments made it possible for some students aged 8-11 to construct expert systems. The major reason for the increased complexity of the shell used in Wideman and Owston's study was the provision of parameters or variables which students found difficult to distinguish from values.

The findings from these studies became available during the design phase of Expert Builder when it had already been decided to implement a rule-based metaphor. Neither of these studies provided objective evidence of learning gains through producing expert system models but both reported that teachers and researchers believed from their observations that the experiences were beneficial for students' learning. In both studies students worked in groups of two or three because discussion and interaction between the students was felt by the teachers and researchers to be useful in this kind of activity.

3.9.6 Implications of empirical evidence of learning by modelling

This review of the empirical evidence has shown that there has been only a limited amount of research into the use of computer based modelling with the exception of work with LOGO. Empirical evidence from work with LOGO was inconclusive. It was not yet proven whether or not using LOGO enhanced pupils' cognitive skills. The more limited studies with other environments had not yet provided evidence for the contribution of computer based modelling to the acquisition of content knowledge and general problem solving skills.

These findings highlighted the difficulties of evaluating the effects on learning of powerful content-free software that could be used in many different ways. These difficulties would also apply to the evaluation of the modelling environment developed in this project. The modelling environment was to be context-free and might be used in a wide range of learning situations to support many different aspects of learning. The evaluation in this investigation was planned as a formative and exploratory one. The qualitative modelling environment was provided to teachers to use in ways which they felt to be appropriate. This enabled a wide range of opportunities for modelling and was based in a normal classroom and curriculum context. In this way it was possible to evaluate the software as a tool for practical classroom applications. The range of learning activities that were developed were then analysed in order to characterise learning opportunities and to identify the types of skills and processes that were required to use the environment.

Some studies provided specific implications for the design of the qualitative modelling environment. Work with PROLOG (Scherz et al., 1990) and with an expert system shell (Wideman and Owston, 1988) showed that students find difficulty in making use of variables. The provision of variables enriches the representation language but may not be desirable for the qualitative modelling environment which is intended to be used by young and inexperienced modellers. This is discussed further in Chapter 4 (Section 4.3.2). In addition the work with PROLOG revealed potential dangers of using a formalism that was very similar to natural language. It suggested that the user-interface design should emphasise the nature of the formalism rather than allowing a possible confusion with natural language.

3.10 Taxonomies of learning skills and objectives

Much of this chapter has looked at theories of how people learn and some of the empirical evidence of children learning through modelling in order to inform the design of a qualitative modelling environment and to consider its position as a learning tool. In this section consideration is given to taxonomies, which although they have been developed for various purposes, share a common theme of clarifying the components of intellectual abilities. In Chapter 2 a framework for the computer based modelling process was defined. A further aim of this research (see Chapter 1, Section 1.3.9) was to clarify the skills and processes that would be needed to undertake this process so that it would be possible to start to develop a taxonomy of modelling that could be used as a practical tool for analysing and developing modelling tasks.

Bloom's taxonomy (1956) of educational objectives has proved useful for teachers in planning lessons and identifying possible learning outcomes although it has been criticised as a detailed approach to higher order thinking skills (Ennis 1987). Two criticisms were: first, the upper levels of Bloom's taxonomy, which could be equated with higher order thinking skills, were too vague, e.g. *analysis* included a variety of skills. Second, the taxonomy was not accompanied by criteria for judging whether the activity was being conducted correctly and Ennis claimed that to teach these skills such criteria were needed. The first criticism is particularly pertinent to modelling since the earlier stages in the modelling process, in particular, would require higher order thinking skills and so any taxonomy would need to represent these at a sufficiently detailed level.

The development and application of frameworks for analysing and classifying different sorts of computer based learning environments is still in its infancy. Some progress has been made by Kyllonen and Shute (1989). Their taxonomy of learning skills was developed in order to analyse the activities of adult learners in computer based learning environments.

Kyllonen and Shute also defined a taxonomy of learning taxonomies:

- Rational taxonomies based on a speculative, rational analysis of the domain where the task categories were defined in terms of characteristics that would foster or inhibit learning or performance. These were the most common type of taxonomy and included Bloom's (1956) and Gagné's (1965, 1985) taxonomies.
- Correlational taxonomies which were primarily empirical and were based on patterns of correlation among performances on learning tasks.

- Information-processing model-based taxonomies which arose from a combination of rational task analysis and the use of computer simulation e.g. Anderson's Adaptive Control of Thought theory (1983).

Kyllonen and Shute (1989) proposed a taxonomy of learning which attempted to integrate these ideas. Their taxonomy was intended as a practical research tool that could be used to classify a learning activity and to assist in thinking more broadly about learning skills and outcomes. They applied their taxonomy to intelligent tutoring systems and they suggested that it could be applied to a wider range of learning activities including classroom situations. Their taxonomy appeared to have an important limitation for the types of group learning situations which were discussed in Section 3.8 in that there was no consideration of the social context of learning. Kyllenon and Shute's taxonomy was based on a conventional view of learning as a process by which a learner internalises knowledge whether discovered, induced by analogy, transmitted from others etc. The possible contributions of social factors were ignored. The taxonomy included a very limited view of variation in learning style but this focused on an individual's cognitive processing and excluded the contribution of any social interaction. Kyllonen and Shute developed this taxonomy with a learning environment in mind where an individual was interacting with an intelligent tutoring system. They limited the scope to characteristics over which the instructional designer would be likely to have control. In general, intelligent tutoring systems omit the social dimension although one approach by Chan and Baskin (1988) included a computer companion as well as a tutor. The lack of a social dimension in a taxonomy of learning was an important omission but, such a taxonomy could provide one means of characterising and comparing computer based learning situations. This possibility is considered in Chapter 9 (Section 9.3).

Ennis (1987) produced a taxonomy of critical thinking dispositions and abilities which would be classified as a rational taxonomy. Critical thinking describes a set of skills and attitudes which were promoted by a reform movement in education in the United States. Ennis reported that statewide testing programs in California, Connecticut, Pennsylvania and Michigan call for the testing of critical thinking at various levels in the public schools. Ennis provided a working definition of critical thinking:

> "*Critical thinking is a reasonable reflective thinking that is focused on deciding what to do.*" (p 10)

Critical thinking could be an aim of education in almost any subject. Certainly the definition above appeared to apply to the modelling process. Therefore Ennis's taxonomy was examined in some detail in relation to some of the modelling activities in the classroom investigation. This is discussed in Chapter 9 (Section 9.4) where Ennis's taxonomy is outlined.

Another theory that was considered in relation to the development of a taxonomy of modelling skills was that of Sternberg (1985). Sternberg's work was different from that mentioned above because rather than developing a taxonomy of learning or thinking skills his purpose was to develop a theory of intelligence. One aspect of this was his componential subtheory, specifying the mental mechanisms underlying intelligent performance. This used the information-processing component as the basic unit of analysis and defined a component as:

> "*an elementary process that operates upon internal representations of objects or symbols.*" (p 97)

A component could translate a sensory input into a conceptual representation, transform one conceptual representation into another, or translate a conceptual representation into a motor output. Each component would have three important properties associated with it:

- duration
- difficulty (that is probability of being executed erroneously)
- probability of execution.

Sternberg identified three kinds of components by function:

- Metacomponents were defined as higher order executive processes used in planning, monitoring and decision making in task performance, e.g. one of the metacomponents identified by Sternberg was "*decision as to just what the problem is that needs to be solved*".

- Performance components were defined as processes used in the execution of a task. Several types of performance components were identified and Sternberg suggested that there were a large number of possible performance components. He cited, as one example of a comparison component, the strategy people use in solving an analogy such as boy:male::girl:? people need to compare the attributes of boy and male in order to determine in what ways these two terms are analogous.

- Knowledge acquisition components were defined as processes used in learning new information, e.g. selective encoding is a component that involves sifting out of relevant and irrelevant information.

The components could interact in various ways. The metacomponents provided the control since only they could directly activate and receive feedback from each other kind of component. The components could be arranged in a hierarchy of tasks with very simple tasks at the bottom, each of which required a set of general, class and specific components. The most complex task at the top of the hierarchy required all the sets of class components as well as the general components and some specific components.

Sternberg's subtheory could be used to generate a theory for any aspect of human intelligent performance. For example, Sternberg produced a componential theory of inductive reasoning by reviewing various empirical studies to identify commonalities across a range of tasks that involved inductive reasoning. He defined the commonalities in terms of seven performance components: encoding, inference, mapping, application, comparison, justification and response. He then supplemented this theory by means of specific models that applied to particular inductive tasks. Whereas the theory specified the components of information processing upon which the models drew, the models specified as well the way in which the set of performance components was combined into a strategy for task solution. He then tested the models by means of a series of experiments in which undergraduate subjects solved reasoning problems of varying levels of difficulty.

Sternberg's subtheory was of interest in relation to computer based modelling for two main reasons. First the modelling process, as outlined in Chapter 2, involved a type of intelligent performance that might be definable in terms of components that were generally applicable to a range of modelling tasks. Secondly the following set of metacomponents, which Sternberg's studies had shown were "quite prevalent in intellectual functioning", also seemed likely to be applicable to modelling tasks:

1. decision as to just what the problem is that needs to be solved
2. selection of lower-order components - choosing a set of components to use in the solution of a task
3. selection of one or more representations or organisations for information
4. selection of a strategy for combining lower-order components - deciding which order to use the components in and to what extent each should be used
5. decision regarding allocation of attentional resources - deciding how much time to spend on each component
6. solution monitoring - keeping track of what has been done, what they are currently doing and what needs to be done
7. sensitivity to external feedback - understanding feedback, recognising its implications and acting upon it.

It was not possible to devise and fully test a componential theory of computer based modelling in the same way as Sternberg had done for three main reasons. First, there was very little empirical data on computer based modelling as it had not been analysed in the same way as general intelligence and reasoning skills so the theory would need to be based on data from this research alone. Secondly, an important aim of this study was to evaluate qualitative modelling within the normal classroom setting rather than attempting to test specific theories of performance in modelling tasks by means of batteries of limited tasks. Thirdly, a computer based modelling task was likely to be near the top of a task hierarchy and to contain a large number of components as it would be a much more complex task than, for example, an inductive reasoning task.

Earlier in this chapter in Section 3.6 various types of reasoning, including abductive reasoning, were discussed and it was suggested that the modelling environment should allow for a range of types of logic and reasoning. It was therefore possible that a modelling task might contain subtasks including various reasoning tasks and other types of tasks. In addition modelling tasks might be so varied that there were insufficient commonalities to enable a componential theory to be developed. Developing a complete theory would be an extensive task but it was possible to use Sternberg's componential subtheory to produce a tentative componential theory of modelling that could contribute towards a taxonomy. This is discussed in Chapter 9 (Section 9.7).

3.11 Summary and conclusions

In this chapter ideas from educational theory and evidence from empirical studies, which have informed the design of the qualitative modelling environment and how it should be used and evaluated, have been discussed.

The accepted constructivist approach to learning exemplified by the Children's Learning in Science Project (CLIS 1987) and by a significant number of researchers provides an appropriate framework for computer based modelling activities. Since children need to be able to express their ideas and knowledge and to evaluate and extend their understanding, a computer based modelling environment would need to facilitate the expression of the learners' knowledge as well as permitting the representation of the relevant aspect of the real world.

The theory of mental models of Johnson-Laird (1983) which proposes that people construct mental models of everything with which they interact was evidenced by users constructing mental models of the situation they were modelling and also of the modelling environment itself. This theory complements the constructivist approach to teaching and learning and is gaining credibility.

The role of a modelling tool should not be to attempt to permit users to copy their own cognitive structures and mechanisms because, even if these were fully understood, it would still be important to consider how the tool could facilitate communication of ideas and probably restructuring of knowledge for different recipients. The modelling tool should help learners to express their knowledge by making the transformation of that knowledge from their own mental models to those of the modelling environment a relatively simple process. There may be benefits for learners in having to examine and restructure their mental models in order to clarify their understanding so that they could then produce external representations. It would be unlikely to be beneficial for learners if external representation entailed significant distortions of learners' mental models into complex knowledge structures and mechanisms that would not normally be used.

The mental models theory also had implications for the design of the modelling metaphor because the user would need to construct a mental model of the metaphor in order to make use of the environment to build a model. This mental model need not be a complete representation of the structure and function of the system but it must be sufficient to enable modellers to structure their knowledge in the modelling environment so that the models would behave appropriately. This suggested that the metaphor should be as easy to understand as possible without compromising its versatility in relation to children's modelling needs.

Some consideration was given to aspects of Piaget's work because it has greatly influenced much educational theory and practice, particularly in the UK. Papert, who has been particularly influential in promoting the use of a computer as a tool in the way that was envisaged for the modelling environment, based his ideas on adaptations of Piagetian theory of learners as active builders of their own intellectual structures. Piaget's stage theory of development underpinned some of the empirical evidence that was discussed in Section 3.8. However, this theory has been called into question by more recent research (Carey 1985a). Vygotsky's emphasis on the importance of social and cultural influences in intellectual development is consistent with Papert's suggestion (Papert 1984) that the child learns computing by being immersed in a computer culture. Vygotsky's work on intellectual development contributed in several ways to this project. First, it supported the idea that using a computer based modelling environment could encourage intellectual development by acting as an instrument of intellectual activity. Secondly, it suggested that it would be fruitful to look for an existing formalism that could be developed so that it might be able to be internalised. Possible candidates for such a formalism, in the context of qualitative modelling, were natural language or some form of logic. Thirdly, the concept of the zone of proximal development suggested that children should be encouraged to work at levels of intellectual functioning beyond what they could easily achieve without support. This contrasted with the Piagetian view of learning that had influenced pedagogical styles in the UK. This 'learning in advance of development' would be possible by enabling social interaction.

Qualitative modelling generally involves some form of reasoning. Research in this area suggests that young children can use simple reasoning so that this presents no barrier to the use of a qualitative modelling tool in children of school age. There is controversy over the nature of human reasoning as to whether it is based in formal logic, everyday reasoning using rules or whether it makes use of mental models. An advantage of rules is that they can be expressed verbally whereas the components of mental models were unknown and they presumably had to be transformed into language. In order to verbalise reasoning a person must use some form of rules so that even if it is proved that people reason by manipulating mental models rather than using rules this does not frustrate the use of a qualitative modelling environment based on rules. The evidence that practical everyday reasoning depends on mechanisms which differ from formal logic is quite compelling and suggests that it would be more appropriate to enable learners to express a range of practical everyday reasoning rather than being restricted by formal logic. Therefore the modelling environment was designed to be as flexible as possible to allow for a range of practical everyday reasoning. The way in which the design could support such reasoning is discussed in Chapter 5.

The possibility of extending an existing formalism in such a way that it may become easier to use and perhaps be internalised, in the way suggested by Vygotsky (1978) and Salomon (1988) was considered. An obvious candidate for such a formalism, in the context of qualitative modelling, was natural language but evidence of work with PROLOG showed that children can become confused by their expectations that entities using human-like language will behave like humans in other ways. The possibility of using a formalism based on some form of logic was considered more likely to help learners to internalise logical methods and hence improve their reasoning ability.

Since evidence has shown that the emotional and social environments for learning are very important, software design should accomodate this as well as being an aid to intellectual development in isolation. Children can learn better in groups but in order to enable appropriate interactions teachers need to adopt suitable strategies for promoting effective group work. The modelling environment should facilitate group work but was not designed solely for group work because teachers might also want to make it available for individual project work. A design feature that would facilitate group interaction as well as individual work was the provision of a diagrammatic presentation of the modelling metaphor which would enable pupils to discuss the structure of the model.

Empirical evidence of children learning and modelling, while not conclusive, provides some support for the hypothesis that modelling can enhance understanding, the development of cognitive skills and the promotion of children's self images as learners. This evidence comes predominantly from work with LOGO and it presents no clear and coherent picture of the skills and processes that are involved in children building models. This was an important aspect of this research and it was reconsidered following the detailed classroom studies resulting in a detailed analysis which is presented in Chapter 9 (Section 9.7).

The inconclusive nature of the results of empirical studies of the effects of using LOGO on children's learning highlighted the difficulties of such endeavours and this would also apply to the evaluation of the modelling environment. The evaluation in this investigation was therefore planned to enable a wide range of opportunities for modelling and was based in a normal classroom and curriculum context. It was also planned to explore the possibilities of using data from the classroom investigation to inform the development of a taxonomy of computer based modelling using the three approaches outlined here of Kyllenon and Shute (1989), Ennis (1987) and Sternberg (1985). The taxonomy of computer based modelling is discussed further in Chapter 9.

Evidence from empirical studies of systems dynamic modelling, by Mandinach (1989) and Brna (1990), which was obtained while the design of Expert Builder was in progress, supported the view that systems dynamic modelling was more appropriate for older students.

The finding by Scherz et al. (1990) that when PROLOG clauses look like English sentences students expect the computer to understand and to reason suggested that although natural language gives a great deal of flexibility it may give certain messages to the children or perhaps support the misconception that computers are intelligent. Studies using expert system shells, particularly that by Galpin (1989), supported the use of a rule based metaphor by showing that some children as young as eight years old could understand the use of such shells.

The study of the literature, discussed in this chapter, has enabled criteria for a modelling tool to be defined. The tool would need to provide knowledge representation facilities which would:

- fit some of the modes of expression that people use naturally. It was important that users would not have to restructure their knowledge into unhelpful formalisms in order to state their ideas.

- require the user to carry out some structuring of their knowledge
- allow easy examination, retrieval and modification of knowledge possibly by being presented diagrammatically.

The tool would need to apply one or more procedures to the knowledge in order to obtain outcomes.

These procedures would need to be:

- able to be viewed by the learners which might be achieved by a diagrammatic form
- comprehensible by the learner
- reconstructable by the learner. Thus they may be able to be internalised and at least the learner will be able to develop a functional mental model of the metaphor.

A computer based tool would be just one component of a whole learning environment. Children learn by being provided with environments where they feel able to express their ideas and test them to see the effects. The learning environment would need to provide a "culture" which was supportive, encouraging and provided feedback in much the same way as the "language culture" of Papert's analogy where the child learns to speak by being surrounded by people who speak. A computer based modelling tool needed to be designed to be part of this environment and to support learners collaborating in groups.

In this chapter the main areas of learning theory that have implications for children building models have been reviewed and this has enabled some criteria for the modelling tool to be established. These criteria were used together with evidence from discussions with teachers and from the review of computer based modelling environments to decide on a suitable metaphor for the new modelling environment. This is discussed in the next chapter.

The view of how children learn that emerges from the literature review and is presented

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Chapter 4 The Modelling Metaphor

In Chapter 2 a review of computer based modelling systems was presented from which candidates for a possible modelling metaphor were identified. Chapter 3 examined theories of how children learn together with empirical evidence of children learning by modelling. It also discussed implications for the design and use of the modelling environment. This chapter combines these two approaches to explore possible metaphors for modelling in relation to the needs of learners and teachers.

The term "metaphor" is used, as discussed in Chapter 1 (Section 1.3), to denote the representational structures together with the functional mechanism that would form the basis of the modelling environment. This chapter outlines and motivates a rule-based metaphor that was selected for the modelling tool.

4.1 The needs of learners and teachers

The criteria established in Chapter 3 for a modelling tool require the design to:

- fit some of the modes of expression that people use naturally
- encourage restructuring of the learner's knowledge
- allow easy examination, retrieval and modification of knowledge
- apply one or more procedures to the knowledge in order to produce outcomes
- use procedures that can be viewed, comprehended and reconstructed by the learner
- fit into the classroom learning environment
- support learners collaborating in groups
- support good current teaching and learning practice.

The Modus feasibility study had addressed this last requirement by examining teachers' views and classroom practice.

In a study by Webb and Hassell (1988), secondary school teachers suggested that children should undertake a range of different types of modelling activity. Webb and Hassell identified two main areas that included most of the types of modelling that teachers felt to be important and were of specific interest to this project:

- dynamic models of a range of systems
- qualitative models of problem solving and decision-making processes

Science teachers, in particular, wanted to use dynamic models but the learning activities mentioned in association with these models were predominantly interacting with the models by inputting values and running simulations. A number of simulation packages were already being used in the schools, often to understand systems that were difficult to study directly. Few teachers felt that their pupils would be able to construct dynamic models because their mathematical skills were too limited and because the relationships to be modelled were quite complex. An exception to this was in the area of advanced level physics where, in the Nuffield Course, mathematical modelling was required. Some teachers were using DMS, the Dynamic Modelling System, with their pupils. Although STELLA overcomes some of the problems of modelling dynamic systems mathematically, studies referred to in Chapter 2 suggested that manipulating the metaphor was still beyond the capabilities of most school pupils. If younger pupils were to be enabled to model dynamic systems an easier technique would be required than that provided by STELLA, possibly one based on a more qualitative approach.

Many of the modelling tasks, suggested by teachers, fell into the category of qualitative models of logical reasoning. These models are based on heuristics rather than precise mathematical relationships and are concerned with relationships between concepts such as causality and dependence. Models of this type can be constructed to guide decision making, diagnose a problem, make predictions and classify objects. Many teachers felt that it would be desirable to provide tools to aid pupils in structuring and ordering ideas and relationships in this way.

Some teachers also commented that the modelling environment needed to allow for pupils to start with fairly unclear ideas. This could be achieved most successfully if the modelling environment provided the flexibility for pupils to rough out their ideas initially and then to rearrange them as their thoughts crystallised. Ideally the metaphor needed to map on to pupils' own perceptions of a situation so that it would not be necessary to distort their thinking in order to structure the model.

In summary the modelling metaphor needed to:

- fit some of the modes of expression that people use naturally while requiring some restructuring of the learner's knowledge and allow easy retrieval and modification of knowledge
- fit into the classroom learning environment and support learners collaborating in groups
- support modelling in one or more of the main areas that were identified by teachers, i.e. dynamic models of a range of systems and qualitative models of problem solving and decision-making processes
- allow for pupils to start with fairly unclear ideas and then to rearrange them as their thoughts crystallised
- map on to pupils' own perceptions of a situation so that it would not be necessary to distort their thinking in order to structure the model.

In the next section the modelling metaphors that were available are compared with the requirements that have been identified here.

4.2 The range of modelling metaphors available

A classification of models was outlined in Chapter 2 and existing computer based tools for modelling were reviewed. From these discussions metaphors for modelling that were already implemented as computer programs were identified:

1. the systems dynamic metaphor using the relational diagrams approach suggested by Forrester (1961)

2. an iterative metaphor for modelling dynamic systems
3. branching story structures
4. a rule-based metaphor embodying formal logic
5. a frame-based metaphor.

The first two of these required quantitative formulation of relationships in order to produce an executable model. There are certain problems with this quantitative modelling. First, the necessary data is often not available, particularly for complex systems such as environmental and social systems. Secondly, some situations are very difficult to model in this way. Many scientific ideas, decisions and hypotheses are based on experience and are qualitative rather than quantitative formulations. For example, a scientist might hypothesise, after a number of observations, that a particular species of snail is more frequent on south facing slopes, but would not expect to apply a mathematical relationship to this. According to Starfield and Bleloch (1986) a method of model building was required that could incorporate qualitative information and knowledge based on experience. Some consideration was given to providing a qualitative facility for modelling dynamic systems because many teachers were interested in modelling these systems but precise mathematical formulation of most of these models was beyond the capability of most school pupils.

The ECO-project (Robertson et al. 1989), attempted to provide a friendly user interface as a front end to a simulation language so that the user could express the ideas for her/his model in a logic-based language that could then be translated into the mathematical relationships required to make the model run. This approach could be useful for enabling the modeller to express some ideas and to obtain a model that makes at least some attempt to represent those ideas so that they can be tested.

The work of the ECO-project was aimed at exploring the possibilities of providing a modelling environment for research scientists and so the techniques and tools used were not directly applicable to school pupils. The possibility of providing a simplified front-end to a design based on the systems dynamic or iterative metaphors for dynamic modelling was considered but rejected for two main reasons. The first reason was that the use of a front end would distance the modeller from the metaphor. The modeller would be at the mercy of the software in that her/his ideas would actually be translated and the modeller would have no control at the level of the functioning model unless the software permitted her/him to examine the model at this lower level. This is always the situation, in one sense. The computer always translates into a lower level language so the crucial question is whether the learner could reach a point where (s)he would not be able to answer important questions about how her/his model was working. There might be ways of alleviating this problem, e.g. by enabling use of the environment at various levels so that modellers could have access to the mathematical relationships if required. However, this approach would be unlikely to be appropriate for younger users. The issue of control of the model is important, particularly for learners who are developing modelling skills and beginning to understand the modelling process. The modeller should feel in control of the construction of the model and be able to work out why particular results are obtained, when the model is run, by debugging her/his own model.

The second reason for rejecting this approach was that a metaphor that was intended primarily for the construction of dynamic models would not provide for the modelling of decision making and problem solving processes that was the focus of this project. The Modus Project decided to develop facilities for dynamic modelling and this work was continued in parallel with the work described in this thesis. The approach adopted for providing this dynamic modelling facility focused on making it as easy as possible for pupils to construct quantitative models by enabling them to sketch out their ideas first and then go on to specify the quantitative relationships. Therefore it provided for an initial stage of qualitative reasoning and discussion. The functional and executable aspects of the model required the modeller to specify relationships and quantities. A long term aim of the Modus project was to integrate the quantitative approach with the qualitative one, the latter being the focus of this thesis.

The branching story structure, rule-based metaphors embodying formal logic and frame-based metaphors can all be qualitative. Branching structures enable the construction of adventure games and event-based simulations such as voyages of discovery. The story-builders that were available were limited by their inability to provide a diagrammatic view of the structure of the story and such a facility would greatly facilitate their use. Discussions with teachers suggested that the use of story-builders was very valuable for stimulating imagination, creativity and divergent thinking. Pupils created extensive branching stories and simulations. This software did not particularly encourage pupils to focus on the decision-making processes. If the software was to be used in such a way the teacher would need to structure the task carefully. LINX88 (Briggs et al. 1988), for example, enables the construction of rules at the branches but pupils generally used simple choices and focused on the descriptions of the events. In summary, although the story-builder approach is one which has further potential for education, it is not well suited to the construction of decision making and problem solving models and models that explore cause and effect.

The rule-based and frame-based metaphors both enable the expression of qualitative relationships and hence allow the construction of models of decision making, problem solving and the analysis of cause and effect. The ECO-project used a rule-based metaphor for the front end to their simulation language but this had to be translated into a mathematical formalism in order to simulate dynamic systems.

The software tools that were available to schools for constructing models using qualitative expressions included logic programming languages such as PROLOG and expert system shells, which were described in Chapter 2. Both of these environments are declarative in approach so that modellers can focus on specifying their knowledge rather than on creating procedural structures. This declarative knowledge could then be used by the system to generate conclusions. A fundamental principle is that declarative and procedural knowledge are kept separate. Significant problems had been encountered using PROLOG in schools including the complex syntax and the lack of graphics. The idea of using an expert system shell was a more promising one but the existing software had drawbacks for children to use to build models. Bignold (1986), McCarthy (1986) and Davies (1986), encountered a number of difficulties in using the expert system shell, Xi, for enabling children to build expert systems as an aid to learning. They concluded that Xi would need some major alterations to make it suitable for use in schools:

> *"The system contains too many facilities and what is required is a critical analysis of those features which are important to schools. These are almost certainly not the same as the requirements for business and industry."*

In studies in secondary schools Webb (1988) and Hassell (1987), found that it was useful for pupils to draw diagrams on paper to clarify ideas. An important conclusion was that a diagrammatic view of the rule structure was desirable, both to assist in the construction of the model and to enable debugging. Galpin, (1989) studied children building expert systems in primary schools. He found that it was necessary to use concrete methods to facilitate abstraction and it was common to use a diagram to show how rules link together. In the study by Wideman and Owston (1988), described in Chapter 3, pupils first constructed diagrams of the system structure on paper before implementing their expert system. A common theme of these investigations was the perceived need to use diagrammatic representations of rule structures.

The studies mentioned above had all made use of a rule-based approach probably because these shells were more readily available to schools. Another study (Valley, 1988) suggested the use of frames as the basis of a knowledge representation language for school children. It was notable that in Valley's study, the applications were classification systems. Frames are particularly useful for representing objects and therefore facilitate the construction of classification systems. However, in order to build a greater variety of models it is necessary to integrate production rules and frames (Aiken, 1983 and Stefik, 1979). The language then becomes much more complex and it is considerably more difficult to provide the model builders with a clear view of how the modelling metaphor works. The frame-based metaphor has potential for use in a learning environment but in order to provide the range of modelling opportunities envisaged in this project, it would be necessary to integrate frames and rules.

In summary, the examination of metaphors that had been implemented as computer programs together with exploration of how they might be adapted for younger users and a limited amount of evidence from empirical studies led to the conclusion that a rule-based metaphor was most promising. This could be a fairly simple metaphor and would allow the construction of a range of models. Pupils had been able to make some progress in constructing models with rule-based tools although existing software had serious limitations. The feasibility study identified the need for a diagrammatic representation of the rule structure. This need was confirmed by evidence from other studies.

4.3 Defining the metaphor

Although the focus of this chapter is on the consideration of possible metaphors, the selection of a modelling metaphor was closely related to user interface design because a guiding principle for the design, which was discussed in Chapter 2, was that it must be possible to present the whole structure and function of the environment visually to the user and enable them to interact with this visual presentation. Decisions about the metaphor needed to be made with reference to key criteria that are summarised below. According to these criteria the metaphor should:

- be based on a simple rule structure
- be represented through a graphical interface that should enable the construction of the model on the screen, using mouse-controlled tools so that the rule structure is clearly shown
- enable an execution trace to be presented to aid debugging
- be sufficiently simple to enable quite young children, who are only beginning to develop abstract thinking ability, to be able to build simple models and understand how they work

- allow as much flexibility as possible in the range of models that can be built without compromising the requirement for simplicity
- allow a range of types of rule based models to be constructed
- allow a range of types of logical expression in order to provide for everyday reasoning.

Following the decision to use a rule-based metaphor it was necessary to consider the possible structure of the rules and how they might be processed. Rules used in expert system shells were generally "IF --- THEN" rules, often referred to as production rules. This simple logical inference can be written in several ways:

A implies B

$A \rightarrow B$

$B \leftarrow A$

IF A THEN B

B IF A

All these express the same relationship between A and B and this simple rule structure enables the expression of most types of rules that people use.

Within the general category of "rule-based" there were a number of possible metaphors depending on what rule structures were permitted. The main issues were:

- which logical operators should be allowed
- whether variables should be available
- whether any mathematical comparators should be available
- how the inference engine should work
- whether weighting factors, certainty factors or probabilities should be allowed
- whether explanation facilities should be provided.

Each of these issues is considered in the following sections.

4.3.1 Logical operators

The logical operators that would normally be considered for inclusion in an expert system shell are AND, OR and NOT. Adex Advisor, which was used in the Modus feasibility study and is discussed in Chapter 2, doesn't allow the use of OR. It is necessary in Adex Advisor to break down a rule containing OR into a number of separate rules, e.g. the rule

take an umbrella IF you are walking AND (it is raining OR it is likely to rain)

becomes two rules:

take an umbrella IF you are walking AND it is raining

take an umbrella IF you are walking AND it is likely to rain

Pupils, who used Adex Advisor during the Modus feasibility study did need to use OR and they found this arrangement of specifying rules rather clumsy. A graphical interface would make the provision of OR easier because a branching structure could be used instead of brackets and it is possible and desirable to allow for OR as well as AND.

4.3.2 Variables

There are two main advantages to being able to use variables when building an expert system. First it enables a question to be compiled in which a range of different values can be input, e.g. *the weather is (wet, dry, cold)* would need to be three separate questions to the user if variables were not allowed. The second advantage is that variables can be used to look up information from a database of facts or from a table. In addition, the eventual linking of the qualitative and quantitative modelling environments would require some kinds of shared data structures and the use of variables that could be accessed and changed by both metaphors would be essential.

PROLOG made much use of variables and much of the work described with PROLOG (e.g. Ennals, 1983) was actually making use of this facility to set up a database. Potential difficulties for pupils in making use of variables were identified and were discussed in Chapter 3 (Section 3.9). A further disadvantage of allowing variables was that some way would need to be found of distinguishing variables, such as underlining, and this would add an extra level of complexity. Adex Advisor contains only a limited use of "pseudo-variables" in that the first two words of a clause are searched when the system is run and questions are pre-compiled so that the three clauses, the weather is wet, the weather is dry, the weather is cold, would become:

Is it true that the weather

is wet?

is dry?

is cold?

This feature enables the modeller to influence how the questions are asked if (s)he expresses the clauses appropriately. The requirement for a simple graphical user interface was considered more important than the provision of variables, and variables would considerably complicate the interface. Eisenstadt and Brayshaw's augmented AND/OR tree (1986), for example, which incorporated variables into a graphical user interface was too complex for most school children to use.

The user interface was designed without variables, in the first instance, although the underlying rule storage mechanism was designed to allow for variables so that in the future this could be provided. The initial design was for an entry level system that could then be extended for more advanced users.

4.3.3 Mathematical comparators

The modelling environment was intended to be qualitative so at the basic level it would not allow for mathematical operations although in future it might be desirable to allow for combinations of quantitative and qualitative modelling techniques. However it is often useful to enable users to provide numbers as answers and then carry out some simple comparisons, e.g. a clause might be *the water is more than 5 miles away* and the system might ask the user to input the distance as a number. This feature is usually provided by expert system shells but its main value is for making the finished expert systems easier to use rather than being important for the person building the model. Therefore this was another feature that needed to be allowed for in future but was not essential for the initial design.

4.3.4 The inference engine

The inference engine for the modelling environment needed to provide an inference mechanism and a search strategy. There are two basic types of mechanism used by most expert system shells; backward chaining and forward chaining (Harmon and King, 1985). A forward chaining mechanism is useful in a planning system where the goal would not be known in advance. A backward chaining mechanism is particularly applicable in diagnostic systems, for example, the patient's symptoms could be input and the inference mechanism would work backwards to determine what condition would produce those symptoms.

An expert system also needs a search strategy in order to determine the order in which the rules will be evaluated. A number of different strategies are possible; the most common ones involve chaining the rules together into a tree structure. Demons are a useful facility that are provided by a number of shells. However, over-use of demons tends to lead to an algorithmic style of programming whereas one of the main advantages of using an expert system, in an educational setting, is to focus attention on the declarative nature of knowledge.

The provision of a range of facilities would make the tool considerably more difficult to learn although it would obviously provide greater flexibility. One of the reasons for the extra facilities was to optimise the search in a large knowledge base and this may be less important for classroom use as the intention was to build small systems. It would therefore be necessary to incorporate control rules. However there could be a need for a choice of forward and backward chaining. Backward chaining is ideal for systems that give advice but children might want to construct models which would allow the end user to supply information and for the system to determine the consequences, i.e. to reason forward from those premises supplied by the user.

The most important consideration in designing the inference engine was to ensure that it was easy for the modeller to understand how it worked. This was achieved by implementing a simple backward chaining mechanism, in the first instance, while allowing flexibility to provide additional facilities in future. The search strategy also needed to be simple and again the depth first search was the easiest to implement and represent to the user.

4.3.5 Weighting factors

One of the suggestions that came from a number of teachers, particularly those in the humanities, was that models should incorporate some system of weighting factors so that some components in a model could be given more weight than others. The main example cited was "Choosing sites", a program that was described in Chapter 2 (Section 2.7.4) and focuses on siting a new development such as an airport or a supermarket. It provides a way of making quantitative comparisons based on qualitative factors. Teachers who suggested this idea were looking for some way of combining this idea of weighting factors or ranking with a rule-based system. If the objective was to rank a number of choices depending on a number of variables that could be considered additively then the technique used in "Choosing sites" could not be improved upon. The reason that teachers were looking for some improvement on this may have been:

1. Some decisions of this type cannot be dealt with in this purely additive way. Some of the factors may be essential while others are additive.

2. The idea of creating such a matrix is rather abstract and is difficult for younger pupils to understand. Assigning values to the factors for each site is also quite difficult and some teachers wanted the pupils to be able to set up their own scenarios rather than using those provided. In the exercises suggested in the

pack the pupils' activities were confined to ranking the factors which as a modelling exercise is quite limited.

In order to provide this kind of facility for assigning values to variables and then summing them, it would be necessary to incorporate variables into the shell and to allow some arithmetic. This is a feature that could be provided but would be no easier to use than the "Choosing sites" program although it could be more powerful.

The technique of incorporating probabilities or certainty factors into expert systems is related to the idea of using weighting factors. The inclusion of probabilities or certainty factors can enable the modeller to weight rules and can also allow the user to express degrees of certainty when answering a question. This could be applied to the "Choosing Sites" problem, e.g. in answer to the question "Does the site have cheap access" the user could answer *yes* with a certainty factor of 7. Most expert system shells incorporate a mechanism for dealing with uncertainty. The two main methods are Bayesian updating and certainty factors. It is quite likely that children would want to incorporate uncertain facts into their expert systems but it is unlikely that having to express the uncertainty on a numeric scale would aid their thinking. The estimation of a probability factor is very hard even for experts and would generally only confuse children and detract from the learning process. A more appropriate technique is that used by the Imperial Cancer Research Group (Fox, 1984). Fox argued that concepts of uncertainty are very rich and varied and very hard to quantify. His approach, which was adopted in Expertech's Xi shell, was to use semantic descriptions of uncertainty, e.g. probably, possibly, might be, etc. This method does not provide a way of combining probabilities from a number of clauses in a rule other than by specifying all the possible rules, e.g.:

> it may be worth taking an umbrella if you may be walking and the weather forecast said there may be rain in some areas
>
> it is probably worth taking an umbrella if you are likely to be walking and the weather forecast said it may rain

This technique is more cumbersome than using certainty factors in that more rules are needed but it is more meaningful to most people.

The design of the shell needed to allow for the use of numerical weightings in the future but this was not a key feature for initial implementation. Pupils would not therefore be able to set up the kind of scenario of "Choosing sites" but they would be able to focus on the important factors affecting the choice of site. They could build these factors into a set of rules and this may be a more important learning activity than ranking those factors.

4.3.6 Explanations

Expert system shells generally provide three types of explanation:

1. Explaining what is the meaning of the question, generated when running the software. This explanation is usually supplied as text by the system builder.
2. Explaining why that question is being asked. The system explains which goal(s) it is trying to prove by showing a trace of the reasoning mechanism.
3. Explaining how the conclusion was reached. This provides a trace of the reasoning that is usually presented in the same order as it was inferred by the system. This makes for a rather clumsy presentation that is not necessarily easy to follow.

Pupils in the Modus feasibility study (Webb, 1988) found the explanation trace in Adex Advisor rather unhelpful. When developing an expert system a graphical trace would be particularly useful to aid debugging. For the end-user, who would usually be another pupil, a graphical trace would be useful to enable the pupil to see how a conclusion has been reached and to help to evaluate the model. However a trace is very limited as an explanation. A domain expert is able to give a wide range of explanations tailored to each individual. A great deal of research effort was being directed towards improving the explanation facilities of expert systems in order to develop effective tutoring systems. An important aspect of this research is the development of user modelling techniques (see Elsom-Cook, 1987). This research is still in the early stages and its application in classrooms is some years away. The difficulty of providing good explanations of how a conclusion was reached was one of the main limitations to children using expert systems to obtain advice. The need for sophisticated explanation facilities in this shell is not very important because the focus of the educational experience would be on building models rather than using them. Nevertheless there is a need for children to have an end-user in mind when building a system and to develop explanations that are suitable for that user. One possible mechanism was that used by French (1987) who designed a "Browser" for a training expert system shell (TEST) with a rule based formalism. The Browser facility allows the knowledge engineer to link concepts, meanings and justifications to rules. The end-user would therefore be able to ask for a deeper justification of a rule or an explanation of the concepts on which a rule was based. This type of facility could be useful for older children but for younger pupils the distinction between these different types of explanations would probably be confusing.

In line with the need for a simple environment the approach chosen was to allow users to provide explanations for individual clauses. These explanations could then be explanations for questions and for the meaning of conclusions.

4.4 Summary and conclusions

Following the review of the range of possible modelling metaphors and the needs of learners a rule-based metaphor was chosen to form the basis of the knowledge representation facility because this could be simple to understand and yet would allow the expression of a range of problem solving and decision making models. Criteria for the design of the qualitative modelling environment based on this metaphor were established and have been discussed in this chapter. A key feature was that the rules were to be represented graphically so that it would be easy for users to develop a suitable mental model of the modelling environment. This approach would also facilitate cooperative work by enabling group members to refer to the graphical representation in their discussions. The graphical presentation of the rules would make the structure easy to understand. Logical connections made graphically would be clear and couldn't be confused with everyday English expressions. In addition the visual representation could show how the rules were chained together and reveal the execution trace. This would increase the learnability of the system and could be used as a debugging facility. The logical operators AND, OR and NOT were to be provided in order to allow for the range of rule structures in everyday use. Variables were not to be incorporated into the initial design of the user interface because they would make the system more complex to learn. However, the underlying rule storage structure was designed to allow for the incorporation of variables in the future. Similarly mathematical comparators and arithmetical operations were also omitted from the initial design of the user interface since these were not essential for simple models but the design allowed for their incorporation in the future. The inference engine was to be based on a simple backward chaining mechanism with a depth first search strategy because this was assumed to be easiest to understand and implement. A limited implementation of simulated forward chaining was also provided (see Chapter 5, Section 5.6.5). A facility to represent uncertainty was to be provided only through semantic descriptions since the evidence suggested that this would be adequate for most situations and it is easy to understand. In addition to the debugging trace, a facility to enable users to provide explanations for individual clauses was provided. It was decided to call the system Expert Builder. In summary the design criteria were:

- The design should be based on a declarative rule-based metaphor.
- The graphical representation should show how the rules are chained together and reveal the executions trace so that it increases the learnability of the system, can be used as a debugging facility and facilitates communication when models are constructed as group activities.
- The interface should provide mouse-controlled tools for model construction.
- The logical operators AND, OR and NOT should be provided.

- Variables, mathematical comparators and arithmetical operations should not be incorporated in the initial design of the user interface but the underlying rule storage structure would be designed so that it would allow for their incorporation in the future.
- The inference engine should be based on a simple backward chaining mechanism with a depth first search strategy that would be easy to reveal to users but consideration should be given to allowing for forward chaining.
- Uncertainty should be allowed only through semantic descriptions since other methods would be too complex for users to interpret and exploit.
- In addition to the debugging trace a facility to enable users to provide explanations for individual clauses should be provided.

Chapter 5 Discussion of Design Issues

The range of possible modelling metaphors and the needs of learners were reviewed in Chapter 4 and it was concluded that a rule-based metaphor should form the basis of the knowledge representation facility. Criteria for the design of the qualitative modelling environment based on this metaphor were established. A key feature was that the rules should be represented graphically so that it would be easy for users to develop a suitable mental model of the modelling environment. In this chapter the design issues are discussed with reference to the technical feasibility and the needs of learners and design decisions are explained.

5.1 The implementation environment

The following were the key criteria for the implementation environment.

- It had to be possible to use the software in some schools as soon as it was implemented because an aim of the Modus Project was to provide software that could be used in schools. Therefore the environment must be one that schools were likely to have or acquire within eighteen months of the start of the project.
- The environment must be powerful enough to support a sophisticated graphical interface and fast processing.
- The environment must be one that schools would be using for some considerable time in the future, i.e. the software must not be developed for an obsolescent environment because it was expected that later versions of the software would be suitable for general use in schools.

The target environment chosen for the implementation was Microsoft Windows because, although this was not very common in schools in 1988, when implementation began, it was expected that this would become widely available in schools by the time that the software was ready for widespread use. At that time some schools were purchasing RM Nimbus 186 computers with 1 megabyte of RAM and these would support Microsoft Windows. The project team included Windows programmers familiar with C and PROLOG. PROLOG would be the easiest environment for implementation of the rule structure and inference mechanism because PROLOG already contains these features. However, at that time there was no implementation of PROLOG available for Microsoft Windows and no versions of PROLOG had facilities for representing sophisticated graphics. C was recommended by Microsoft as providing the best performance with Windows and so this was chosen for the final implementation.

Consideration was given to possible prototyping in a rapid prototyping environment but at that time no suitable environment was available. PROLOG was the easiest environment for prototyping the inference engine but the school trials of Adex Advisor (Webb 1988) had already enabled evaluation of a simple text-based expert system shell and the evaluation of improvements to the rule storage structure and inference mechanism would be of limited value without the graphical user interface. The latter was the more difficult aspect of the design and there were no quick prototyping facilities available for linking a graphical front-end to a PROLOG shell. Some non-functioning prototypes of parts of the user interface were implemented in Hypercard in order to discuss possibilities within the project team. However it was felt that in order for teachers and pupils to be able to comment on the design more fully they would need a functioning version.

5.2 Outline of the design task

The design task involved two aspects:

1. the design of the basic shell structure including the underlying rule storage structure and inference mechanism
2. the design of a user interface that would facilitate users in developing a mental model of the modelling metaphor as discussed in Chapter 3.

These two tasks were interdependent because the user interface was intended to enable the users to make use of the modelling metaphor but at the same time the ability of the users to work with the user interface would determine the complexity of the metaphor that could be used. As stated by Norman (1986) "*what makes a good user interface viewed from the user's side is often the fact that there is a good conceptual model behind the system that is made apparent in the system image*". A guiding principle for the design, which was discussed in Chapter 2, was that it must be possible to present the whole structure and function of the environment visually to the users and enable them to interact with this visual presentation.

In Chapter 4 a consideration of the needs of learners established a set of criteria for the design that were listed in Section 4.4. Each aspect of the design is considered in the following sections. In the next section the rule structure diagram is discussed. This was considered first because it was the most important feature of the user-interface and the structure of the shell would be largely dependent on how the diagram was to be presented.

5.3 The rule structure diagram

The rule structure diagram would present the metaphor to the user in a diagrammatic way that would help her/him to develop a mental model of the metaphor and to communicate with others about the structure of the model. It needed to include the clauses of the rules and they could be confined in boxes so that they were clearly delimited. They needed to be constructed into rules using some kind of links and logical operators. In PROLOG-based expert system shells rules were usually of the form *A if B* but some teachers (including some in the study by Galpin (1989)) had suggested that *if B then A* was more natural. These teachers were considering writing individual rules rather than looking on the model as a branching rule structure so their suggestion may not apply to this design. In a branching rule structure *if B then A* may not be so easy to use because it suggests that the rules will be evaluated by forward-chaining and it may be more difficult to focus on the goals of the model and hence to give it some purpose. One of the strengths of Adex Advisor, revealed in the Modus feasibility study (Webb, 1988), was that it encouraged modellers to focus on the purpose of the model because in order to make it run it was essential to designate at least one clause as an "advice clause" that the inference mechanism would use as a goal.

The first decision was how to arrange the boxes and there were four possibilities as shown in Figure 5.1. Arranging the model across the screen as in (iii) and (iv) had attraction in that building a model from left to right is customary but working from right to left is much less natural and the intention was to enable both ways of working, i.e.:

- starting from the goals and then specifying the conditions
- starting from the conditions and then specifying the conclusions.

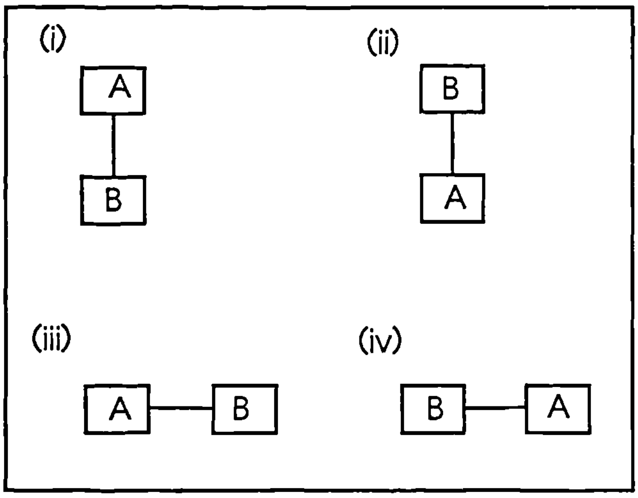

Figure 5.1 Possible arrangements of clause boxes for the rule *A if B*

Arrangement (i) would be an obvious choice if the rule structure was intended to be interpreted as *A if B*. It would also have the advantage of having the goals at the top of the structure so that they would be easy to find and it would encourage users to focus on the purpose of their model. It would tend to encourage the creation of advisory models but it would enable other types of models, such as those concerned with fault diagnosis and planning, to be built although in these situations the modeller would probably start building at the bottom of the screen. Arrangement (ii) would be more intuitive if the rule structure was intended to be interpreted as *if B then A* but the goals would always be at the bottom of the screen or possibly off-screen at the bottom. It was expected that advisory models would be the most common model type because work with Adex Advisor, during the Modus feasibility study, suggested that a wide variety of models could be built in this way. If the modeller were intending to build an advisory model (s)he would probably start by specifying at least some of the goals and so it would be easier if these were at the top of the screen. There would be no reason why (s)he should not build both up and down the screen depending on whether (s)he was working from the goals or from the conditions. Building the model up or down the screen seemed to be acceptable and since advisory models were expected to be most common it was decided to use arrangement (i).

The next decision was whether to include *if* on the diagram. This would give an immediate clue to the nature of the diagram, e.g. it could be shown as in Figure 5.2 but it would restrict the interpretation of the rule structure to A if B and thereby reduce the flexibility of the environment because although functionally there need be no difference in the way the system worked, viewing rules in this way would always tend to encourage modellers to start from the conclusions and then determine the premises. Therefore *if* was omitted from the diagram.

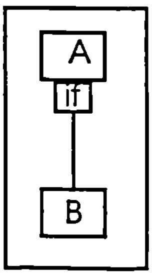

Figure 5.2 Incorporating *if* on the diagram

A further consideration was whether to use arrows as connections between the clauses to show some directionality in the logic. The obvious use of arrows would be to show logical implication. This was not something with which the proposed users of the environment would be very familiar and it was more likely that they would interpret it as a flow chart since these were used in schools for various purposes. This interpretation might lead to a variety of problems in thinking about the metaphor and developing an appropriate mental model so it was decided that the links should be simple threads and when "reading" the diagram the modellers should be encouraged to think of rules such as *A if B* or *if B then A* depending on the nature of their model.

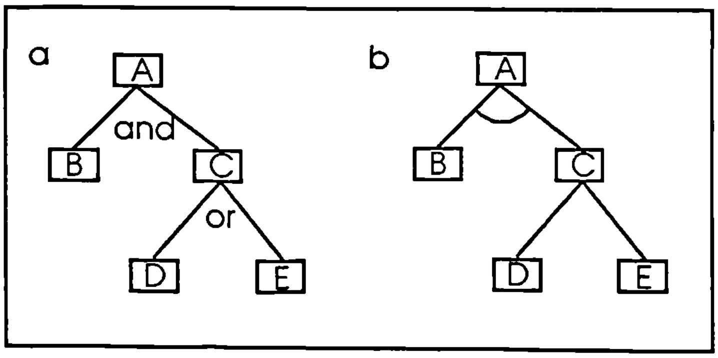

Figure 5.3 An and/or tree

On a typical and/or tree the logical operators are often shown in the forks of the tree as in Figure 5.3a or as symbols as in Figure 5.3b.

The logical operators would be more clearly distinguished as part of the logical structure by being in boxes and this would also make them easier to position. The modeller would then need to take care to link them thoughtfully into the structure and would therefore focus on the logic in the model. The rule structure diagram was therefore designed as shown in Figure 5.4.

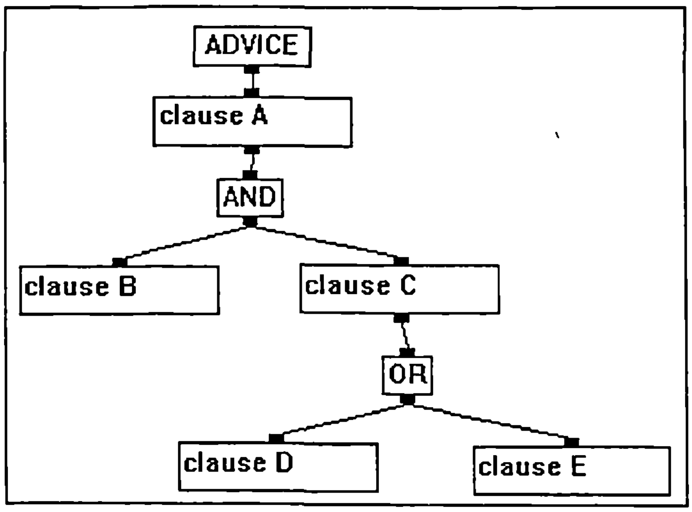

Figure 5.4 Design for the rule structure diagram

5.4 The basic shell structure

Once an outline for the diagrammatic representation was established it was necessary to consider how the rule structure could be implemented. Detailed information about implementation techniques for expert system shells in C were not available in the research literature since shells for research purposes were usually implemented in PROLOG and although some commercial implementations were in C, information was not available from these commercial organisations. Therefore it became clear that in order to design an interpreter in C, for the inference mechanism, expert help was needed. This was obtained from Paul French at Kingston University who had built several expert system shells for training. The outline design for the rule structure diagram, together with the other criteria for the shell were discussed with Paul French and the Modus software engineers in order to decide how the basic shell structure should be designed and what other factors needed to be considered. The basic design was driven by educational considerations but the detailed design needed to be negotiated with the software engineers in order to match technical feasibility and performance-related constraints with educational needs.

5.5 Rule storage

A first consideration was to ensure the separation of declarative and procedural elements. French commented that some commercial expert system shells mix declarative and procedural information. They might, for example, contain a rule:

animal is insect IF *ask* number of legs AND number of legs is six

which would force the system to ask the user the number of legs when that rule was used. This type of structure would be a severe disadvantage in an educational expert system shell where the intention was to encourage pupils to express their knowledge rather than to write a procedural program. The rule storage method needed to be fully declarative so that the user could focus on expressing the knowledge rather than concerning themselves with how the system would work. It would be possible to generate questions automatically from the knowledge base or to provide annotations to the knowledge base separately from the basic knowledge structure. In the initial design the questions were generated automatically since this is simplest for modellers to deal with but this does not preclude the possibility of providing a facility, in a future version, to annotate the knowledge base so that modellers would be able to structure questions.

According to French (1988), implementing rules as inclusive or's is straightforward but implementing exclusive or's in C is very difficult. Each rule would therefore be tested and more than one might fire. This could be advantageous because many problems have more than one solution and pupils should be encouraged to look for alternative solutions.

The initial design did not contain variables, so each clause was either true or false, for example, in the rule shown below the statements enclosed in brackets would be treated as clauses that are either true or false.

(take an umbrella) IF (it is raining) AND (you are intending to walk)

When an entry was typed into the system it needed to be stored in a dictionary structure where there would be one entry for each sequence of words so that if a user typed in the same item twice it would only be stored once. A method of exact pattern matching was therefore needed. Entries needed to be split at IF and AND so some means needed to be found through the user interface of facilitating this. The initial design outlined above enabled this.

The rules, which would be stored by the shell, were of the form:

<clause> [IF [NOT] <clause> {AND [NOT] <clause>}]

where [ ] enclose optional items and { } enclose items that may be repeated. French suggested that the provision of the logical operator OR in the rule structure would be through the user interface but the rules would need to be converted into the above form for storage.

French designed a data model for the rule storage, see Figure 5.5 and this was then adapted and optimised by the Modus team's software engineers to make the best use of Windows data structures.

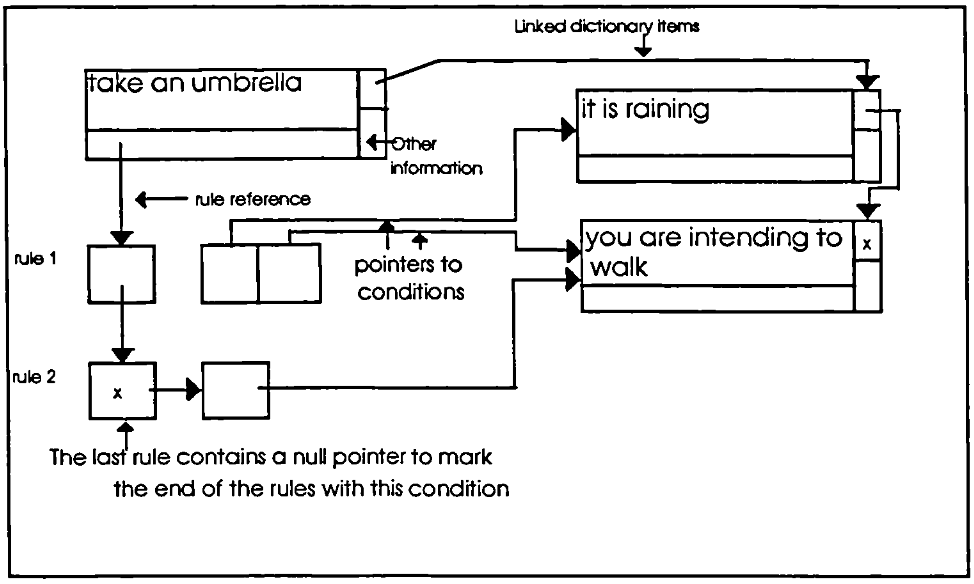

Figure 5.5 French's data model for rule storage

5.6 The inference engine

The basic function of the inference engine was to prove a goal to be true. Formal logic provided rules for deduction:

- If A then B. A. Therefore B. This is the classical law modus ponens
- If A then B. Not B. Therefore Not A. This is the classical law modus tollens.

The chain rule was an extension of modus ponens in that it took an argument forward by generating a new true implication, rather than forward to just a new proposition.

Given : $A \rightarrow B$

Given: $B \rightarrow C$

Deduce: $A \rightarrow C$

Modus ponens provided the basic law to be used by the inference mechanism together with the chain rule that enabled rules to be chained together to provide a series of logical inferences.

According to French it would be extremely difficult to implement logical negation and although there were theorem-provers that could do this, they were several orders of magnitude slower than a simple implementation of negation by failure. Since system performance was an important consideration for the final implementation and there appeared to be no educational disadvantages with this strategy it was decided to use negation by failure. This meant that the inference engine would test all the rules related to a particular goal and if none of them fired it would set that goal to false. The system therefore behaved as a closed system so that if a conclusion couldn't be shown to be true, it was designated as false. For example if there was only one rule, "if A then B", when A was false the inference mechanism would decide that B was false. This was not an implementation of modus tollens because if another rule existed, if C then B, the inference engine went on to test this rule and if this fired, B was set to true. It was still possible to use semantic methods to prove a statement to be false by, for example using a rule such as:

> the site is not a good site for a settlement IF
> water is far away AND
> woodland is far away

According to French, the inference engine needed to do the following:

> For each condition:
>> check that it is true
>> remember that it is true
>
> For each group of rules
>> select a candidate rule
>> check that its conditions are true

The following strategy was used to check that a condition is true

> a condition is true if it is known to be true
> a condition is true if it can be proved to be true
> a condition is true if the user says it is true (the system needs to remember this)

The inference engine also needed a search strategy that, as explained earlier, was based on a simple backward chaining mechanism with a depth first search since this was likely to be the easiest strategy for modellers to understand and was also relatively easy to implement. The rule structure shown in Figure 5.6 would be searched in the following way:

> The initial path is a b c e
>
> If e fails the system must backtrack to the last decision (c) so the system must remember the path.
>
> The path is then c—>f
>
> If f fails the system must backtrack to the last decision (c) but there are no other options available at c so for normal execution purposes this decision point would be forgotten and the system backtracks to b.
>
> The path is then d—>g.
>
> If g fails the system backtracks to the last decision (d).
>
> The path is then d—>h.
>
> If h fails the system backtracks through d and b to a.
>
> The final path is a—>i.

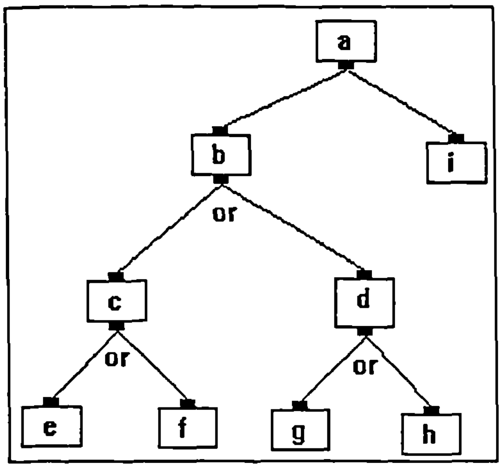

Figure 5.6 A rule structure

For the normal functioning of the inference mechanism, the system needed to remember the state of each condition on the way down the tree but forget when it backtracked. Therefore the system would remember unconditionally until it was told to forget. However since the intention was to provide a trace of the execution process, it was necessary to remember the state of all clauses for this purpose. It was decided that the most efficient technique would be to design the interpreter so that it could store all the information required for the trace of the reasoning but provide facilities for it to work in different modes so that a rapid execution run could be performed, when required, without storing extra information. The main reason for these considerations was speed of performance, which was expected to be an issue for the final implementation.

The strategy outlined above would not necessarily result in a rule firing; it was possible that all the rules tested would fail. In this circumstance the system would be unable to come to a conclusion unless a "catch-all" mechanism was implemented. The provision of such a facility would introduce a procedural element into the system in that this must come into effect when all the relevant rules had been tested and failed. Again the solution chosen was the simplest so that when the system was unable to prove any more goals true it would inform the user. The justification for using the simplest mechanisms as far as possible rather than opting for more sophisticated solutions was that it was expected that the modeller would generally find it easier to develop a mental model of a simpler mechanism and it would be easier to present to the modeller graphically. This information would not be context sensitive but the modeller could implement her/his own "catch-all" simply by making it the last rule to be tested and ensuring that it always fired.

The basic technique for implementing this search strategy involved using two stacks, a success stack and a failure stack. The success stack would keep track of where the search had reached in the structure and the failure stack would keep track of where the choices were so that the search could return to that point when a proof failed.

5.6.1 A note on variables

Although it had been decided not to implement variables in this first version of Expert Builder, the intention was to allow for their future implementation. A major issue was whether local variables or global variables would be required. PROLOG uses local variables that are specific to a particular rule and only used by that rule. If local variables were required they would need to be stored on the stacks and this would considerably complicate the stacks. Global variables would not be associated with the stacks so it would be easier to allow for future implementation of these. It was difficult to see any major advantages of using local variables within this environment where modellers would probably view their model as one coherent structure and would therefore be more likely to expect variables to be global. In addition a further aim was to provide links with other modelling metaphors within one integrated system and here it was expected that global variables would be used. The decision to allow for global variables rather than local ones considerably eased the problems since, according to French, this would require only fairly straightforward modifications to the rule storage structure and the inference mechanism would be equally suitable. The major design issues for this proposed future change would be concerned with the user interface.

5.6.2 The interpreter for the inference engine

The algorithm for the interpreter was designed by French (see Figure 5.7) and adapted and optimised by the Modus software engineers. In summary, the algorithm was designed to enable:

- the application of modus ponens and the chain rule to the stored rules
- a backward-chaining depth-first search strategy
- storage of information about which rules had been used for the solution, when required, so that a reasoning trace could be provided
- more than one solution to be provided to the user by imposing a failure and re-entering the loop at *if the condition is not true*
- variables to be introduced in a future version of the software.

Interpreter Loop

```
rule pointer := goal rule:   /*point to pseudo rule*/
condition pointer :=first condition of current rule;

loop:
if there is a next rule
    create fail stack entry recording:
        a pointer to the next rule,
        and the current top of success stack pointer;

successloop:
while the condition pointer points to a condition
{
    /* check that each condition in the body of a rule is true */
    if there are rules which define the current condition
    {
        /* use the rule to check if the condition is true */
        if there is a next condition
            create a success stack entry recording a pointer to the next condition;
        rule pointer := first rule for this condition:
        condition pointer := first condition of the current rule;
        /* to remember which rules were used to get an answer, record the current rule pointer on
    the failure
        stack at this point */
        goto loop;
    }
    else
    {
        ask if the condition is true;
        if the condition is not true
        {
failure:
            if the failure stack is empty
                /* if this point is reached then there are no more alternatives */
                return fail;
            /* reset the value of variables here using the reset list entries */
            pop the failure stack re-instating:
                the previous rule pointer,
                and the previous top of success stack pointer (provided that this is earlier in the
    stack
                than the current top of success stack pointer);
            condition pointer := first condition of the rule;
            goto loop;
        }
        else
            increment the condition pointer to the next condition;
    }
}
if the success stack is empty
    /* if this point is reached then we have verified that all the conditions are true */
    return true;
pop success stack re-instating the previous condition pointer;
goto successloop;
```

Figure 5.7 Algorithm for the interpreter

5.6.3 Calling the interpreter

A further decision concerned when the interpreter would be called. An important design criterion was that the user should be able to execute the model at a high level so that it would come to a decision and provide advice. In this way the model could have a particular purpose to provide advice about a specific problem or to assist in making a decision. It had already been decided to provide the facility to designate certain clauses as advice so that they would become the set of goals when the system was asked for advice. In addition users might want to ask specific questions of the system, i.e. they would want to ask whether a specific clause was true or false. This facility would also be useful for testing parts of the model. The interpreter would therefore be able to be called in two ways:

1 by asking for advice

2 by setting a particular clause as a goal.

5.6.4 Unknown clauses

In the preceding discussion it was stated that clauses are either true or false. This would need to be the case for the inference mechanism to function because a goal could only be proved or negated when the precise states of the clauses were known. However, for the user, it may not always be possible to answer a question so they may want to answer "don't know". According to French, this could be treated in two ways by the interpreter:

1 The search could fail at this point in which case the assumption is being made that goals can only be proved true if all the necessary information is provided.

2 The search could succeed at this point and the answer is then being taken as unimportant. There may be some situations where a user wants to say that a particular answer is not needed, i.e. they really want to answer "don't care" rather than "don't know".

This dilemma was resolved by considering what would be easiest for the modeller and user to understand. The modeller was to be encouraged to specify the rules as clearly and precisely as possible so that, as far as the modeller was concerned, there would be no suggestion of asking unnecessary questions. The modeller would be designing the model to require definite answers. Enabling *don't know* to be taken as either true or false would probably be very confusing to the modeller. There was no difficulty, through the graphical interface, in showing clauses in more than two states. Four states would actually be needed, true, false, unknown and untested. The algorithm, designed for the interpreter, would enable the state of each clause to be stored. It was still necessary for the inference mechanism to either succeed or fail when an unknown clause was reached. Clearly, if the mechanisms were allowed to succeed, it would be possible for users to answer no questions as true or false and still obtain a result and this would not encourage pupils to think carefully about their answers. Therefore the inference mechanism was designed to fail when an unknown clause was reached but the fact that the failure was a result of an unknown clause was stored so that, if no goal fired, the user could be informed that this might be because not enough information was available.

5.6.5 Forward chaining

A system that always proceeds through backward chaining and therefore asks all the questions each time it is run can be rather tedious for a user who may think that some of the questions are irrelevant. A user may wish to volunteer certain answers and then ask the system to draw its conclusions using this data. Certainly, when a modeller was testing her/his model (s)he would want to be able to supply different sets of data and see the output quickly and easily. Pupils using Adex Advisor (Webb, 1988) became irritated with this need to run through all the questions each time the model was executed and they became careless in supplying their answers. Therefore the possibilities of implementing a forward chaining mechanism were explored. A real forward chaining technique would be data driven rather than goal directed so it may result in many alternative solutions. This could lead to problems, when designing a model, in deciding what solutions should be presented to the user. Another major educational drawback of implementing real forward chaining was that two different reasoning mechanisms would need to be presented to the modeller and (s)he would have to decide which to use in particular circumstances. The provision of both inference mechanisms obviously required implementation of a second interpreter which would have increased the work involved in implementation. An alternative approach, suggested by French, was to simulate forward chaining by running the backward chaining mechanism without asking questions, i.e. all unanswered questions would be assumed to be unknown. The system would therefore draw conclusions from the answers already supplied, if possible. This method seemed to provide the facilities needed without increasing the complexity of implementation and without burdening the modeller with another inference mechanism.

5.7 Logic and reasoning supported by Expert Builder

In Chapter 3 the various types of reasoning and logic were discussed and it was concluded that, although the precise mechanism of human reasoning was not fully understood, everyday reasoning was more flexible and less precise than formal logic. Expert Builder was therefore designed to be as flexible as possible in supporting a range of types of reasoning that were in everyday use. In this section the range of types of logic and reasoning, that were discussed in Chapter 3, are re-examined to explore how well they were supported by Expert Builder .

Expert Builder embodied a representation of propositional logic. Rules in Expert Builder were in diagrammatic form but could be interpreted as

$A \rightarrow B$

where A could contain multiple statements connected by AND or OR and could be prefixed by NOT. The inference mechanism made use of modus ponens and the chain rule. The inference mechanism in Expert Builder behaved as though it was a closed system so that if a conclusion couldn't be shown to be true, it was designated as false. For example in the simple system, shown in Figure 5.8 , when A was false the inference mechanism would decide that B was false.

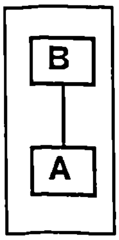

Figure 5.8 A simple rule diagram

Expert Builder therefore was not strictly adhering to formal logic. A clause in Expert Builder could be any statement that could be designated as either true or false. It was possible to include some notions of modality by using statements such as:

> the rock **may be** limestone
>
> the pollution is **possibly** due to car exhausts.

When the inference mechanism operated it needed to assign either true or false to each statement so there was no uncertainty possible at this level.

The reasoning mechanism of Expert Builder would not allow the non-monotonic reasoning in Toulmin's model (Toulmin, 1958). It would be possible however to express most of the reasoning from the example given in Chapter 3 in a simplified form as shown in Figure 5.9.

Patient has straight forward URI(D)----------------------------> presumably (Q), Patient needs penicillin (C)

Straight forward URI's need penicillin treatment (W)   unless allergic to penicillin (R)

Clinical experience (B)

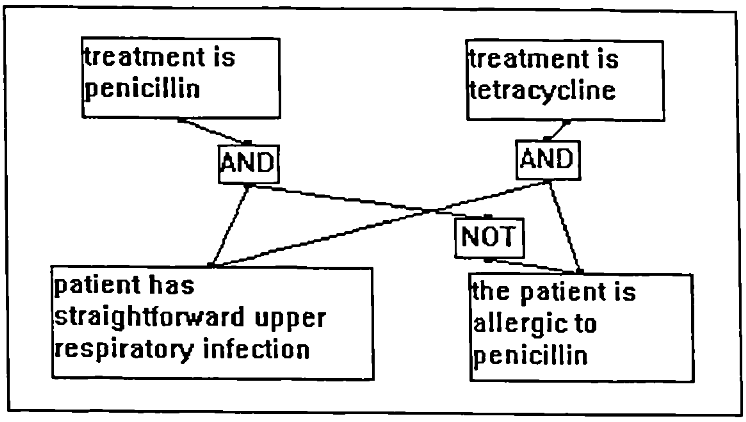

Figure 5.9 Reasoning based on Toulmin's model and how it could be implemented in Expert Builder

The modeller could employ the logic suggested by Toulmin in creating this structure although this would not be fully represented in the model in that the *basis* for the decision could not be included without explanations for rules, i.e. it would be necessary to explain the rule:

> *treatment is penicillin if patient has straightforward upper respiratory infection and not patient is allergic to penicillin.*

by an explanation that stated that this was based on clinical experience.

5. 7.1 Plausible reasoning

The plausible reasoning described by Collins and Michalski (1989) might be involved in the construction of a model but would not be completely captured, e.g. the model shown in Figure 5.10 might result:

Q:	*Is the Chaco cattle country? I know the cattle country is down there (in Argentina).*
R:	*I think its more sheep country. Its like western Texas, so in some senses I guess its cattle country.*

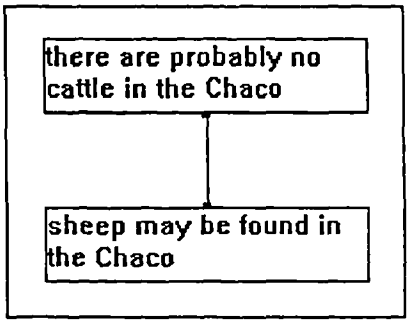

Figure 5.10 How Collins and Michalski's reasoning might be partially implemented

The other premises in this argument are the justification for this rule. The design of Expert Builder does not allow the expression of explanations for rules.

The propositional logic on which Expert Builder was based could support both deductive reasoning and inductive reasoning as shown in Figure 5.11

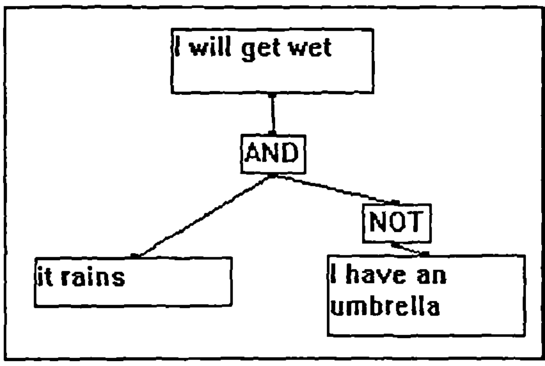

Figure 5.11a Deductive reasoning structure

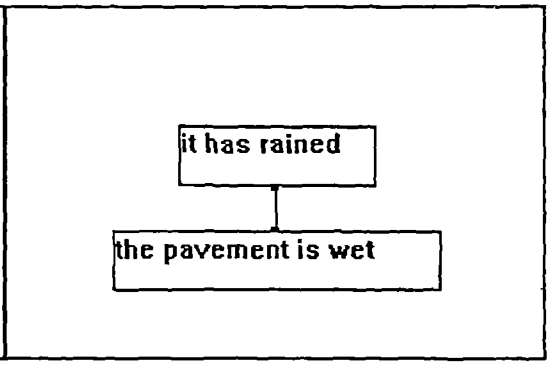

Figure 5.11b Inductive reasoning structure

Abductive reasoning may be the most common reasoning process when building models in Expert Builder because a typical task would be to provide advice about a problem. Therefore the modeller would usually, although not exclusively, start by considering what are the possible advice statements and then, by abduction, decide how to conclude that the advice is appropriate.

The example of practical logical reasoning (Braine and Rumain, 1983), mentioned in Chapter 3, Section 3.6.3, could be expressed in Expert Builder as shown in Figure 5.12. The significant point here is that in order to express this rule in Expert Builder the whole rule set needed to be made explicit whereas in human reasoning assumptions would be made. This was a strength of Expert Builder because it would encourage learners to be explicit and to state their assumptions.

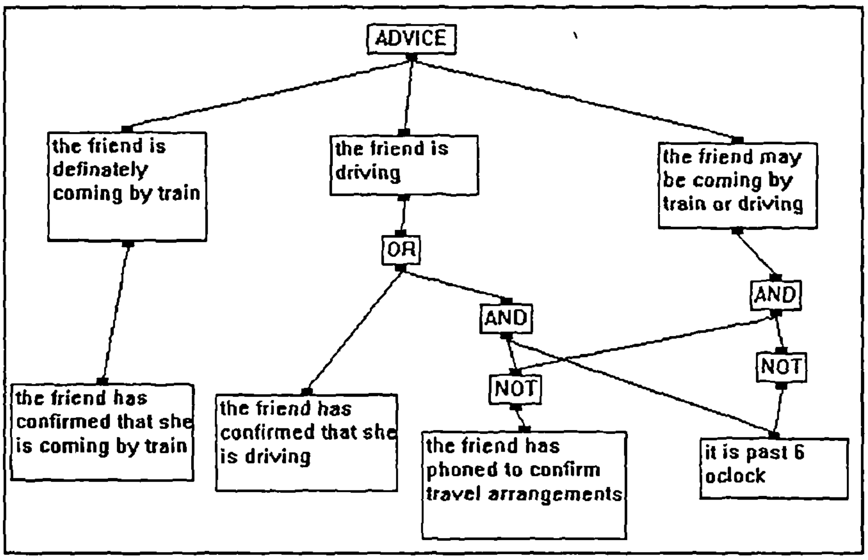

Figure 5.12 An example of practical logical reasoning

5.8 Detailed design of the user interface

The design for the modelling metaphor was now established and the rule structure diagram was designed. There were already certain constraints on the user interface design. The software was implemented in Microsoft Windows which imposed a basic user interface design. When Expert Builder was designed, Windows was just emerging and the guidelines for the design of Windows programs were still somewhat vague. More recently, standard names for menus and the more common menu commands have emerged. The standards and guidelines that were available were followed because the more overlap there is between applications the easier it is for a user to become familiar with a new application. This is particularly important for teachers who have so many other pressures on their time that they can't devote a lot of time to learning a new software package.

5.8.1 Building a model

The main consideration was to enable the modeller to build the diagrammatic structure. The use of mouse-controlled tools seemed to be the easiest way to enable this construction since pupils were already using such tools effectively in painting and drawing packages. The tool palette was designed as a tear-off menu, similar to that used in Hypercard, since this could be positioned anywhere on the screen thus enabling the modeller to make best use of limited screen space.

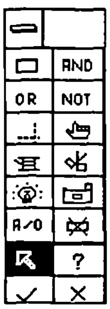

Figure 5.13 The tools

When a tool was selected the cursor would change to the tool shape. The top four tools in the tool box were for creating and placing clause boxes and logical operators. The modeller needed maximum flexibility in positioning boxes so that a wide variety of model structures would be possible and the modeller could start anywhere on the screen. The diagrams might become fairly large so a scrolling window was used.

The tool was for sizing clause boxes and worked by dragging the lower right corner of the box. This technique was chosen in place of that employed by many drawing packages where "blobs" appear when a block is selected and they can be dragged to size the object in any direction (see Figure 5.14). This was because a number of fairly inexperienced users of drawing packages, particularly teachers and some pupils, had been observed to have difficulty using this "standard" technique for sizing because the area of the "blobs" was very small and it required very skilled mouse manipulation with few advantages over the technically easier method that was chosen.

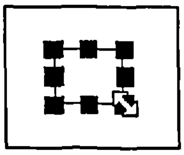

Figure 5.14 A standard technique for sizing boxes

The tool was designed for moving boxes by dragging. The was for designed joining ("threading") boxes together because it was a non-threatening idea, suggesting something fairly easy and it was not masculine in its associations compared with other suggested tools, such as spanners. There were various ways in which the direction of the dependency in the link could be shown. The possibility of using arrows had been ruled out owing to the danger of mistaking the structure for a flow chart. Another possibility was to use the position on the screen so that the box higher up the screen would always be the conclusion in the rule. The disadvantage of this was that unless the modellers were constrained to a grid they could cause themselves and others confusion by placing boxes ambiguously. The technique that was chosen was to make the link from the lower half of one box to the upper half of another as shown in Figure 5.15.

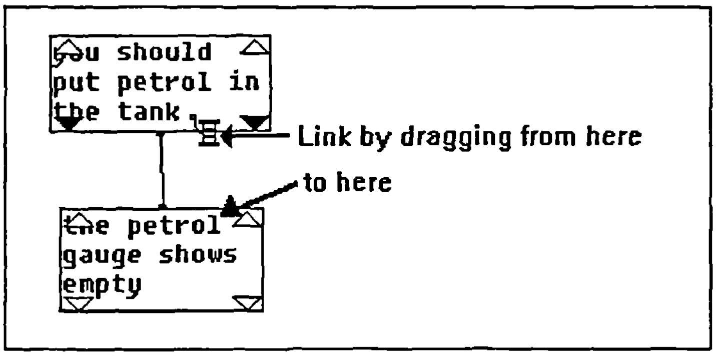

Figure 5.15 Linking two boxes

The diagram would be clearer if the boxes were placed appropriately but once the link was made it retained the same meaning even if the position of the boxes was reversed. A link was made by dragging, with the 𝌆 from one box to the other. A thread appeared when the 𝌆 was dragged and the link was made when the mouse button was released provided that it was appropriately positioned. When the 𝌆 was selected arrowheads appeared in the boxes and they became highlighted when the 𝌆 was over that half of the box so that the modeller could see when (s)he was in the appropriate part of the box. The details of this method were decided after several attempts at prototyping. Observations of pupils using drawing packages suggested that the majority of pupils would have no difficulty in manipulating the tools but a minority might find some of the mouse manipulation difficult so it was important to make the operations as simple as possible. In particular it was essential that modellers were given detailed feedback particularly about the position of the tool because inexperienced users tended to make jerky mouse movements. The thread was created by a click and drag action rather than a simple click because if they had started the thread from the wrong place simply releasing the mouse button would remove it. Another possibility would have been to fix the end of the thread at the first click and then move the cursor to the other end of the link and click again. The latter technique might lead to pupils inadvertently starting threads. The need to drag to the appropriate position, whilst being perhaps the most difficult action in the system, would ensure that the modeller concentrated on linking correctly.

The original intention was to enable the scissors actually to cut the threads anywhere along their lengths but the software engineers regarded this as difficult to implement particularly in view of the fact that a number of threads might overlap. In the first instance, therefore, it was agreed to implement a technically easier but less user-friendly method where a thread was removed by clicking on the box at each end of the link.

The light bulb tool created advice boxes that could be attached to any clause to make it a goal of the system. Unlike most of the other tools the use of the light bulb tool was not expected to be intuitively obvious. There appeared to be no icon that obviously represented "advice" so the light bulb was chosen as it was fairly distinctive, could be associated with advice and would not lead users to expect it to have any other function.

The camera tool was designed for copying boxes. Clicking on a clause box with the camera caused the cursor to change shape and when it was clicked again on the screen an exact copy of the box was placed. This would enable the modeller to build the model in subsections so that the diagram could be neatly organised (see Figure 5.16). The duplicate boxes would behave in exactly the same way as the original.

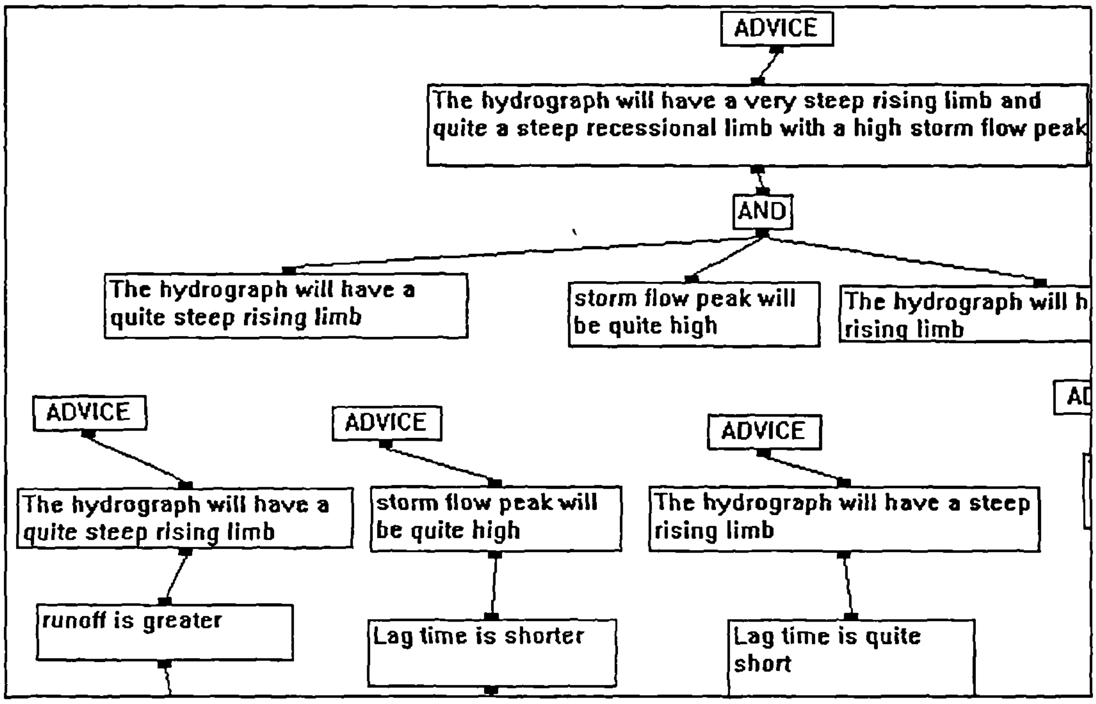

Figure 5.16 Arranging the diagram using duplicate boxes

The A/O tool was added to the tools after some initial trials with a few teachers when it was found that they would change their minds about whether an AND or OR was needed in a particular rule. The A/O tool changed an AND to an OR or vice versa simply by clicking on it rather than having to delete the operator, make a new one and remake the links. The tool was designed to delete a box and its links by clicking on the box.

5.8.2 Testing the model

The other tools were designed for running and testing the model and they were also available from a smaller tool box that occupied less screen space (see Figure 5.17).

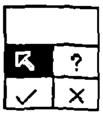

Figure 5.17 The Use tool box

The question tool (?) could be clicked on an advice box to "ask for advice". This called the inference engine and set all those clauses connected to advice boxes as search goals. They were evaluated from left to right on the screen. When a goal fired it was presented to the user as advice in a dialogue box.

When the inference engine was called it worked through the mechanism outlined earlier and coloured and/or shaded the boxes as they were found to be true, false or unknown. The colour and or shading could be set by the user and a key was available via a menu command. In the normal mode, when the inference engine reached an unknown clause, for which there is no condition, it would present it as a question to the user in a dialogue box, shown in Figure 5.18.

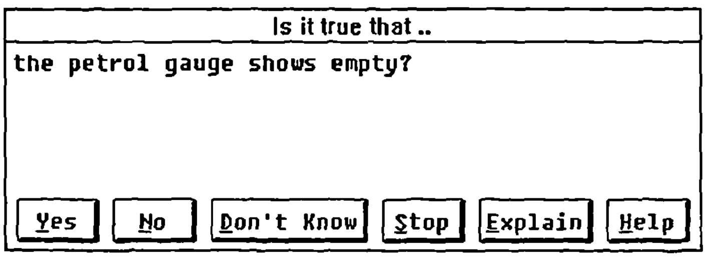

Figure 5.18 The Question dialogue box

If the user had asked for advice, when the inference engine proved a goal to be true, an advice dialogue box would be presented to the user as in Figure 5.19.

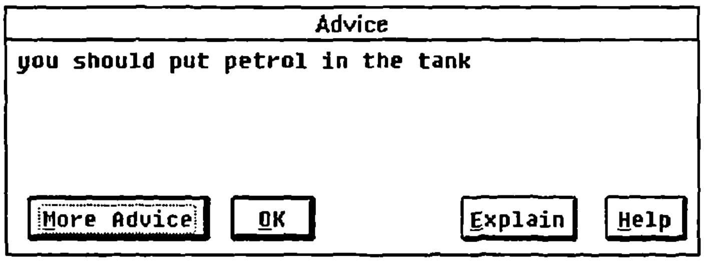

Figure 5.19 The Advice dialogue box

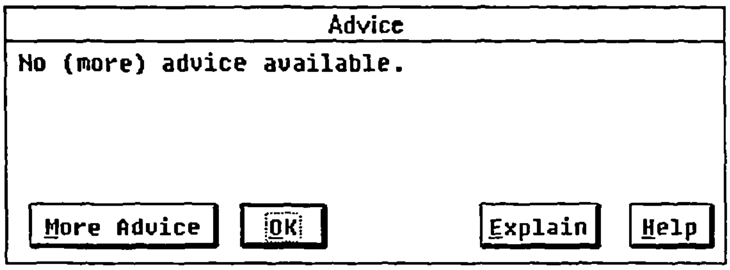

Figure 5.20 The dialogue box presented when no more advice goals could be proved

If **More Advice** was chosen the inference engine would try to prove the next advice goal. When no more advice goals could be proved the dialogue box shown in Figure 5.20 would be presented.

5.8.2.1 Asking questions

The inference engine could also be called by clicking on any clause which was then set as the goal. In this case the clauses were simply coloured and/or shaded as the engine worked through the rules. This would enable the modeller to test subsections of the model and it would also facilitate the use of models.

5.8.2.2 Volunteering answers

The tick and cross could be clicked on any "leaf" clause, i.e. those with no conditions to volunteer them as true or false. In this case when the inference engine was called it would set all clauses for which answers had not been volunteered to unknown and evaluate the model using those answers given. If the inference engine was called by asking for advice, when it reached the end of its search the dialogue box shown in Figure 5.21 would be presented. This facility enabled quick testing of the model.

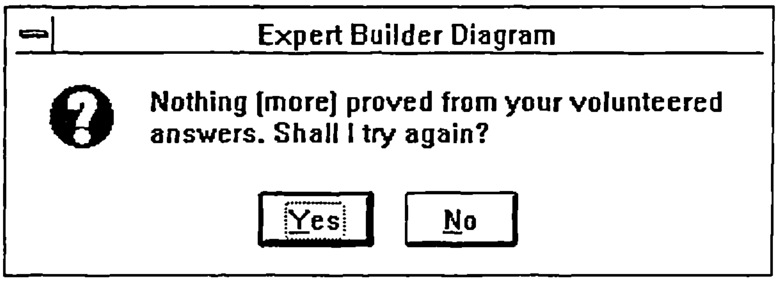

Figure 5.21 The dialogue box presented when no more goals could be proved, in volunteering mode

5.8.3 Explanations

A dialogue box was provided in which modellers could choose any of the clauses that they had written, from a list, and then either type an explanation or paste in a picture that had been produced in a painting program. Explanations were available, when the model was run, either via an Explain button in the question and Advice dialogue boxes or from a menu command. The button was greyed when no explanation was available.

5.8.4 Long View

One of the problems that was immediately apparent with this modelling environment was that models were likely to occupy more than the size of one screen and that modellers would need to be able to keep in mind an overview of the whole structure of their model and move around quickly on a model that would probably spread over several screen widths. This was particularly obvious with the relatively low resolution screens that were widely used in schools at that time. Ideally the modeller should be able to "zoom" the model to various magnifications but this was technically quite difficult. The solution chosen was a "long view" that could represent the whole of the model on the screen at once showing the outlines of the boxes with no text (see Figure 5.22). This facility would be useful for testing the model because the coloured trace could be seen on the long view so the modeller could find out where errors in the logic were occurring. The dotted outline on the long view showed the current main screen view and this could be dragged to scroll the screen. This technique was intended to facilitate modellers in finding parts of the model and it was also a much faster method of scrolling than using the scroll bars. Questioning and volunteering could also be done on the long view. Obviously the latter facility would only be useful if the modeller knew the structure of the model well and hence could locate particular boxes without seeing the text but this could be achieved by referring to a printout of the model.

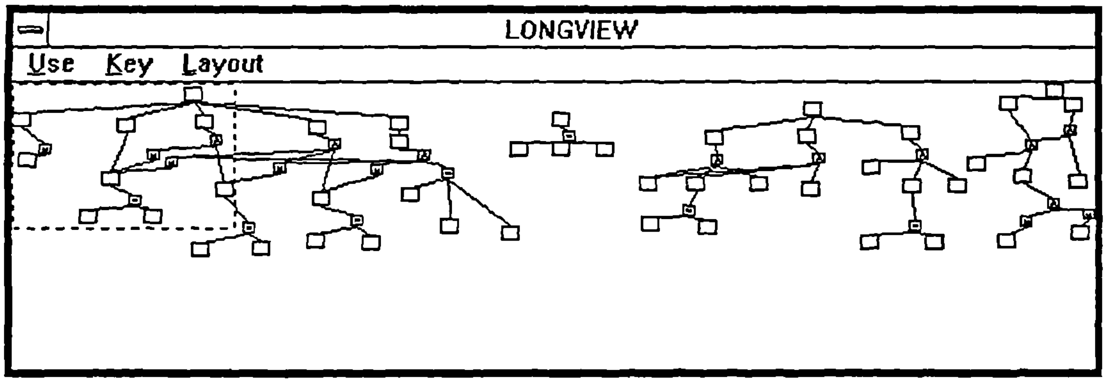

Figure 5.22 The Long View

5.8.5 The reasoning trace

The diagrammatic trace of the reasoning was shown automatically on the screen when the model was run. The interpreter also allowed for the presentation of the trace textually. However this facility was not provided to the user because the trials of Adex Advisor (Webb, 1988) had shown it to be of very limited value and sometimes to confuse. Therefore in this implementation the user would be forced to focus on the diagrammatic trace in order to examine the reasoning.

5.9 Other facilities

The facility to provide a title page for the model, consisting of text or graphics, was provided so that pupils could present their finished model with a page describing its purpose and perhaps who should use it and how. This was considered to be important to encourage pupils to make their models for others to use and to enable them to present them well.

The boxes contained the normal Windows editing facilities including the ability to cut, copy and paste text to the Clipboard. These facilities were also available in the Explanations Editor and the Title Page Editor.

It was originally intended to implement full printing facilities so that it would be possible to print out any parts of the model, but in order to reduce development time the printing facilities were restricted. The main omission was the implementation of the printout of the full model diagram. Facilities were provided to print the Long View, the rules in their condensed textual form and the textual explanations. A facility to save the rules and explanations as a text file was provided so that pupils could use the test when writing up projects.

Help buttons were provided in the dialogue boxes and these gave context sensitive help, i.e. the information provided changed depending on the users current options. Help was also available about the menu commands and the tools by selecting the menu command **Help With Menus** that caused the cursor to change to an H that could be clicked on a menu command or a tool to receive help about that item.

The program gave error messages for all illegal operations. The most significant messages were those that were produced when there were mistakes in the rule structure and these were generated when the rules were stored, i.e. when the model was run. Messages appeared as shown in Figure 5.23.

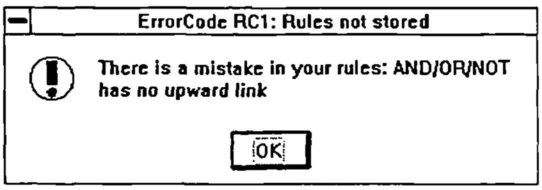

Figure 5.23 The error message generated when there was a mistake in the rule structure

A guide to using the software was produced containing a tutorial section, a teacher's guide and a reference section (Integrated Modelling Project 1989). The guide included a framework for constructing a model that was used as a basis for a tutorial on how to construct an advisory model. This framework was based on the description of the modelling process discussed in Chapter 2 but it was adapted to make clear how it could be applied to the construction of an advisory expert system. Figure 5.24 shows how the modelling process was presented.

The Modelling Process

Step 1 Identify and define the problem.
Step 2 Identify the possible solutions which might be given to the user as advice.
Step 3 Decide what are the main factors affecting the problem.
Step 4 Define rules which specify under what conditions a particular piece of advice applies.
Step 5 Test the system and alter it as appropriate.
Step 6 Examine your rules and see if they need to be specified further.
Step 7 Repeat this process from step 3.

Figure 5.24 The modelling process as specified in the Expert Builder Guide

5.10 Technical requirements for running Expert Builder

The compiled version of Expert Builder required Microsoft Windows 2.0 or later and occupied approximately 200K of disk space. The program could be run from a floppy disk on a machine with at least 640K of RAM provided that there were two 720K disk drives since it was also necessary to run Windows from one of the disks. A machine with a single 720K floppy drive could only be used if it contained at least 1.5 MB of RAM in which case some memory could be allocated as silicon disk for storing the program and parts of Windows. In these conditions disk storage space for models was quite limited.

5.11 Summary of design decisions

In this chapter detailed design decisions have been discussed and justified in terms of the design criteria which were established in Chapter 4. Design decisions were made for four main reasons. In some cases the reason was purely pragmatic in that other solutions would be too complex or time consuming to implement. The method of linking boxes, was experimental in that there was no clear evidence or guiding theory on which to base the choice of method. Therefore the method was chosen based on intuitive ideas about what children would be likely to find easiest to use. Evidence for the ease of use of this technique was sought in the first stage of the evaluation discussed in Chapter 6. Design decisions are summarised in Table 5.1.

Table 5.1 Summary of design decisions

Decision	Reason for decision
Arrangement of boxes to express rule	expressivity
Use of AND, OR and NOT	expressivity
IF not to be specified on diagram	expressivity
Link from lower half of conclusion box to upper half of condition box	expressivity
Links to be lines rather than arrows	experimentation
Advice boxes to specify conclusions	expressivity
Mouse-controlled tools	usability
Following MS Windows conventions	usability
Tear-off tool palette	usability
Simple but limited sizing technique	usability / pragmatism
Scissors action	pragmatism
Bobbin action - dragging thread to link	experimentation
Camera to copy clauses	expressivity
Volunteering answers	usability
Explanations for clauses	expressivity
Long view	usability
Not a comprehensive zoom facility	pragmatic
Title page facility	expressivity
Ability to answer question with Don't know	expressivity
Backward chaining	usability
Inclusive OR's	pragmatism
No variables in initial design	usability
Negation by failure	pragmatism
Interpreter to be called task ask advice or to ask question	usability
Automatic generation of questions	usability
No catch-all	expressivity
Allow for global but not local variables in stack design	usability / pragmatism
Not full forward chaining but simulated forward chaining	usability
2 modes for interpreter - remembering search details or not	usability

Most of the design decisions were made to maximise either the range of expression that would be possible (termed expressivity in Table 5.1) or the ease of use of the environment (termed usability in Table 5.1)., In two instances the choice was limited by pragmatic considerations although it was based on ease of use.

Chapter 6 Evaluation - An Initial Study

In Chapter 5 the design issues for Expert Builder were discussed and the implementation of the software was outlined. The software was developed as a fully functioning system. This could be used as a prototype for evaluation of the educational potential of qualitative modelling. In this chapter an initial evaluation of the software is discussed. This evaluation was part of a wider initiative undertaken by the Modus project which involved setting up a network of teachers to discuss computer based modelling. This included sending a questionnaire to members of this network. The questionnaire was extended for the purposes of this research. In this chapter the questionnaire survey is described and discussed. In addition, a pilot study of the software in classroom use is described.

6.1 Methods and rationale

Since computer based modelling was new to most teachers, a very small minority would have had experience of quantitative modelling using software such as DMS, the Dynamic Modelling System, and very few would have encountered qualitative modelling. The Modus Project therefore wanted to encourage discussion of modelling issues among the wider education community to enable a range of educational users to contribute ideas for the design of modelling software. To facilitate this, educational institutions were invited to join the Modus Club, set up in October 1989, in order to exchange ideas on modelling and to trial Modus software. They were charged £20 annual membership fee for which they received three newsletters over the year, the Expert Builder software and the manual.

The Modus Club was used for this study in order to obtain some initial response to the design features of the software and to identify schools which were candidates for more detailed study in the next phase of the evaluation.

A questionnaire was designed (see Appendix 1) in order to:

1. provide basic information about the institution that could be included on a database for future mailing.
2. enable participants to express general views on modelling and on the types of software facilities that they would like. This information might inform future Modus developments.
3. provide feedback on the documentation in order to inform future Modus developments.
4. provide information about the participants' prior experience of modelling software in order to provide a context for their comments.
5. enable participants to express their initial reactions to the metaphor of Expert Builder and its potential for classroom use.
6. enable participants to grade features of the user interface according to their usefulness.
7. allow participants to comment on any facilities of the software and to identify features that they would like to see included.
8. encourage participants to try out Expert Builder with their students and to send in any comments and suggestions about its use with students.

Objectives 4 to 8 were included specifically for the purposes of this study. The questionnaire was sent as soon as an institution joined the Modus Club. This was intended to encourage as many members as possible to provide feedback rather than to be passive members. It was therefore only possible to collect initial reactions after people had tried out the software and perhaps in a few cases given it to some pupils to use. Nevertheless this initial reaction was important in order to see whether teachers could identify any potential in the software and to determine whether any of the features were particularly useful or particularly problematic in the initial stages of use. These initial stages are very important for any software, but especially for educational software since most teachers are so busy that if a piece of software proved difficult to start to use, most teachers would probably not persevere. In addition, the level of access to computers for most school pupils was still very low in 1991. Many pupils would have generally only a very limited time to use any one piece of software. Therefore they needed to be able to start using a piece of software as quickly and easily as possible. On the other hand regular users of a particular type of software could be expected to spend time learning to use a piece of software if they believed that it would provide the functionality that they required.

There was an additional sheet for participants to fill in with regard to students' work. A revised version of the questionnaire, slightly extended to include comments about use by other teachers, was sent out with the second Modus newsletter. Members were also encouraged to send examples of classroom use and further copies of the classroom use sheet were sent. Approximately 18 months after the Modus Club was set up a telephone survey of secondary school members was carried out by a secretary. The main purpose of this survey was to identify potential participants for a trial of another Modus product but it also provided feedback that was relevant to this study.

6.2 Results of the questionnaire survey

The Modus Club was started in November 1989. By January 1991 there were 140 members from a range of institutions as shown in Table 6.1.

Table 6.1 Membership of the Modus Club

Type of Institution	Number	Percentage who returned questionnaires
Higher education -general	24	17%
Schools of education	13	31%
Further education	12	8%
Sixth form colleges	1	100%
Advisory centres	27	11%
Secondary schools	39	21%
Primary schools	5	40%
Unclassified	19	0%

The members in higher education included both schools of education undertaking initial teacher training and other departments. These are shown separately in the Table 6.1. Out of the total of 140 members 23 had returned their questionnaires and of these six had provided examples of models that they had built.

The returns spanned the range of institutions involved as shown in Table 6.1. The relatively low number of returns meant that the results could only provide some very tentative information about teachers views of the potential of this style of modelling and usefulness of the software features. In follow up phone calls 13 secondary schools who had not returned questionnaires were contacted. Only one of these gave a negative reaction to the software. He said that he didn't find Expert Builder as useful as other software, such as spreadsheets, that he was using for modelling. Three said that they had not been able to look at the software, either because of lack of appropriate hardware or lack of time. Eight had viewed the software briefly and were intending to look at it again but complained of lack of time. One was finding the software very useful but had not had time to return the questionnaire. These results suggested that the low response rate is likely to be due to factors such as lack of time and insufficient access to appropriate computer systems rather than to any very negative reaction to the software.

The objectives of the questionnaire relating to its purpose for the Modus Project (numbers 1 to 3 in Section 6.1) were only partially fulfilled owing to the low numbers of returns. Nevertheless a small number of individuals did express views that were taken into account when planning and designing software. Some members of the Modus Club, who used Expert Builder in their classrooms, sent example models and more detailed reports (see Webb 1990a, 1990b, 1993 and 1994b). The results of the questionnaire survey that relate particularly to objectives 4 to 8 of the questionnaire are provided in detail in Appendix 2 and are summarised here in the following sections.

6.2.1 The potential for qualitative modelling in education

A majority of those who returned questionnaires (15 out of 23) were experienced computer users who already used computers for modelling with a range of software. Many were teachers who were responsible for Information technology in the school or college. However, eight of the returns were from teachers who had little or no experience of computer based modelling. 18 out of the 23 respondents were intending to use Expert Builder with their pupils. Of the five who did not intend to, one said that its use would be too time consuming and the others said they did not have any opportunity to do so. Most of the respondents could see various difficulties in introducing the use of Expert Builder to other teachers, ranging from problems with resources to changes to the teaching/learning style, e.g.:

> *"There is a lack of hardware - Windows and mice"*
>
> *"Teachers need familiarity with the Windows environment"*
>
> *"Expert systems need a lot of confidence"*
>
> *"Teachers need to modify their approach to teaching, changing from a delivery style to an exploratory style"*

Similar comments were made by teachers who attended workshops where they worked with Expert Builder for 1-2 hours. The majority of teachers who attended these workshops said that they thought Expert Builder could be useful in their subject but they saw similar problems in introducing it to those listed above.

The Modus Club was continued throughout 1990 and 1991 and was then gradually wound down owing to lack of resources. It is not possible to be precise about the extent of use of Expert Builder during this time. The response from the questionnaire and from follow up phone calls suggested that teachers were interested in the idea of modelling and saw potential in the use of Expert Builder. However they were limited by time constraints in their experimentation with Expert Builder in the classroom. They also needed help to get started.

6.2.2 Responses to design features

Comments on the design were generally favourable with most of the respondents finding the diagrammatic representation generally easy to understand and use. Table 6.2 summarises the responses to key design features. Four of the five key features identified in the questionnaire were considered to be useful or very useful by a majority of the respondents. The diagramatic representation of the rules was considered to be useful or very useful by 95% of the respondents. Approximately half the respondents felt that the ability to provide a title page was unnecessary.

Table 6.2 Responses to key design features

Design feature	Percentage of respondents who found this useful or very useful
The ability to represent rules diagrammatically	95%
The ability to see a trace of the reasoning on the diagram	95%
The ability to provide your own textual explanations of clauses	86%
The ability to use pictures to explain clauses	67%
The title page facility	48%

There were some adverse comments and suggestions for improvement. These related to features that had not been implemented or only partially implemented for pragmatic reasons, e.g. the action of the scissors and limited printing facilities. Another potential problem highlighted was that of dealing with larger models. Some respondents commented that the diagram could become spaghetti-like and suggested that a better zoom facility would help. They wanted to be able to work on a smaller scale diagram where they could still read the text. This was technically difficult to implement but might be possible with higher resolution screens. There were also comments on the performance on networks and slower computers. Features that had been implemented for reasons of expressivity and/or usability and attracted some adverse comment or alternative suggestions were:

- the default processing from the left
- the fact that arrows for implication were not used
- the method of making links

- the arrangement of rules on the screen - conclusions being at the top of the screen.

These features were considered again in the detailed evaluation described in Chapter 8, Section 8.2.3 and 8.3 and 8.4.

6.2.3 Comments on classroom use

A range of topics was suggested for computer based modelling and those who hoped to use Expert Builder mentioned a wide range of different topics for target groups from nine years to adult. 62% of respondents reported that they had used Expert Builder with their students. The comments about classroom use were nearly all very positive, e.g. some are quoted below:

> *Worthwhile for getting students to think logically about a task. Best to get students to plan on paper first.*
>
> *First expert system shell seen which could realistically be used in a cross curricular context. All others are far too difficult to use.*
>
> *Children found it fun and had little difficulty with the tools but the metaphor was hard.*
>
> *Some conceptual problems. Technically OK.*
>
> *Slow to start but students learnt very quickly. Good learning for students, vocabulary extension and exact use of words.*
>
> *Students found it very interesting and enjoyed the intellectual challenge. It is a splendid and entrancing bit of software with huge potential*

The questionnaire responses and correspondence with some members of the Modus Club suggested that there were a small number, probably about ten teachers who were using Expert Builder fairly extensively with their classes. This fairly low level of use was not unexpected. The trials version of Expert Builder was not intended for general use and it was made clear to club members that it was only a prototype. The reason for the wide scale trial through the Modus Club had been to find some keen teachers, from a variety of educational institutions, who were prepared to work with experimental software and to put up with the frustrations of bugs and limited printing facilities. One respondent commented that *"the overall finish of the product was too crude to introduce to staff who lack confidence with software"*. Experience of advisory work in Hertfordshire schools, by the Advisory Unit for Microtechnology in education, had shown that teachers needed a great deal of support to take on a new use of information technology involving a new piece of generic software. The ImpacT project (Watson et al., 1993), a three year study started in 1989, which set out to evaluate the impact of IT on children's achievements reported (page 3):

> *"The use of more general purpose software, such as spreadsheets and databases and programming, placed additional demands on the teacher, beyond that of becoming familiar with the use of the more complex software. These demands included more reflection on the nature of the subject and the potential role of such software in enhancing processes and understanding."*

Despite these difficulties associated with introducing a new idea into schools and the many demands on teachers' time the overall response to the basic concept of Expert Builder and its potential for use in the classroom was very positive. One teacher commented:

> *"Students found it very interesting and enjoyed the intellectual challenge. It is a splendid and entrancing bit of software with huge potential."*

6.3 A pilot study of classroom use

The questionnaire survey was used to provide some pointers to the range of potential uses of the software. It also highlighted some of the possible problems and limitations in its use. The returns from the questionnaire survey were used to identify potential schools for detailed classroom study and to identify some areas for further investigation. A pilot study was conducted in order to identify issues for detailed investigation in a more extensive classroom study. The aims of the pilot study were:

- to identify the problems students encountered in learning to use the interface

- to identify the problems students encountered in using the modelling metaphor
- to identify the interactions which occurred with the software and between students while using Expert Builder
- to develop a methodology for recording and classifying students interactions while using Expert Builder and the nature of the problems they encountered.

The study is described here and the conclusions are discussed together with implications for the design of the main study.

6.3.1 Selection of participants

Several primary as well as secondary school teachers showed some interest in using Expert Builder. In particular, two primary teachers had previously used Adex Advisor for a research project. It was decided to carry out the pilot study with one of these schools for the following reasons:

- it was better to focus on the younger end of the age range, for which Expert Builder was designed, since the pupils would generally be at an earlier stage of intellectual development than older pupils. They could be expected to find more difficulty in developing a mental model of the metaphor and in making use of the interface than older pupils. Therefore there would be more chance of revealing most of the problems that might be encountered in making use of the interface and metaphor in the early stages of using the software.
- the teacher was fairly confident in using the computer in the classroom and although not familiar with Windows felt sufficiently confident to allow the children to explore for themselves.
- there were fewer time constraints in primary schools. Teachers felt able to spend some time trying something new, whereas the secondary school teachers were concerned about completing the syllabus. Although the national curriculum requirements were beginning to change this situation, only the core

national curriculum subjects had been implemented in primary schools when this study was conducted.

- it was possible for a class to work on a topic for a longer time slot than in a secondary school where students would generally have one period per week of about one hour to work on a subject. It was felt that the possibility of using the software for a considerable amount of time was essential because as with any general purpose software, a reasonable amount of time would be needed for users to begin to exploit the potential of the software.

6.3.2 Preparatory work

The study took place in a small primary school in a rural community where the children were drawn from a range of backgrounds. The class used in the study was year 5 (age 9 to 10) which consisted of 17 children. The study was carried out during time when the children normally worked on a variety of tasks associated with their topic work, mainly individually, but with some discussion. One computer was available to this group. The teacher was visited by the investigator and shown the main features of Windows and Expert Builder during about one hour. Disks were provided to autoboot Expert Builder and Windows. The computer was a 1 MB Nimbus PC2 so the software had to run off floppy disks. The teacher decided to try to build a system about the Battle of Hastings as a class exercise. The class had been studying the battle and had written accounts of it. They had a class discussion about what factors led to success in the battle and they decided to group their ideas under 3 headings - tactics, strategy and equipment. The teacher then constructed this basic model in Expert Builder (see Figure 6.1), thereby demonstrating how to use the software.

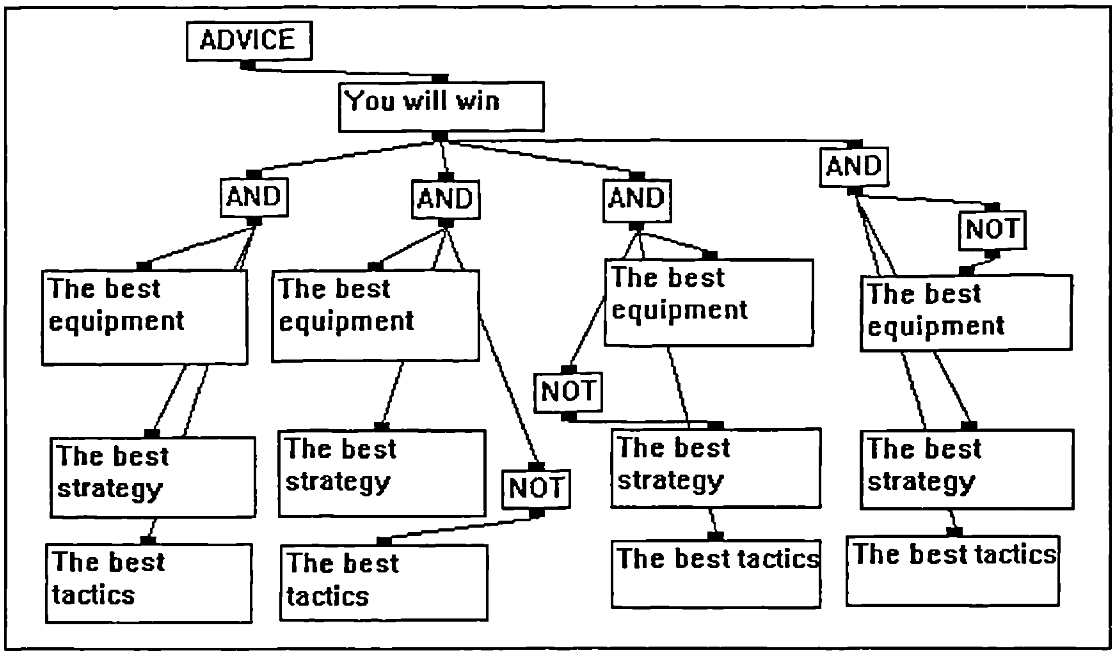

Figure 6.1 The first model about the Battle of Hastings built by the teacher

Subsequently, children went on to specify parts of the model in more detail, working in groups of 3 or 4 (see Figure 6.2).

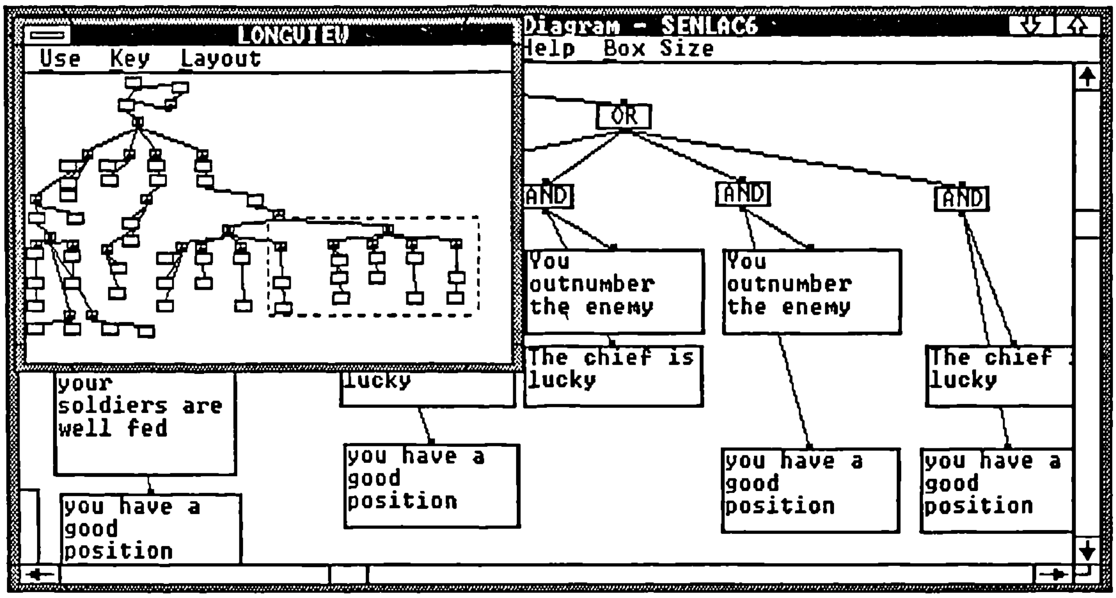

Figure 6.2 The final model about the Battle of Hastings after it had been worked on by the pupils

This work took about 4 mornings and was spread over several weeks. During this time the school was visited twice, each time for about one and a half hours. These visits were used to support the use of the software and to carry out some preliminary observations. The teacher asked a number of questions about the use of the software. Some of these were concerned with the normal operation of the software. Other questions resulted from bugs and other problems with the software. These were corrected before the main study, which is described in Chapters 7 and 8, started. The teacher and pupils were observed using the software but the sessions were not recorded. The children were given a lot of help in using the tools and in deciding what to include in their model.

6.3.3 The main task

After this model had been completed, the teacher decided to use Expert Builder, to build a model during their next topic, habitats and conservation, again as a class exercise. The school grounds contained a number of small areas which were managed in order to maintain them as particular habitats. The purpose of this work was to study the habitats and the species they contained and to consider how the habitats are managed. The teacher decided to use Expert Builder during the work as a focus for consolidating the knowledge gained during the study.

The class began by visiting each habitat and noting what species were present. They were introduced to the idea that certain species are typical of particular habitats. They discussed the management that was carried out in each habitat and the reasons for the methods used. They made notes in their rough books. The habitats included woodland, a pond, marsh, hay meadow and hedgerow. The school grounds were next to farmland, where they noticed skylarks.

Each pupil had a project folder in which they wrote descriptions of each habitat. They also worked through a series of "project sheets", on subject matter related to the environment, e.g. nutrient cycling, photosynthesis, the water cycle, etc. Each had a short explanation of a process and a diagram. The pupil's task was to copy the diagram and find the meanings of a number of key words.

The teacher decided that the system should be built to provide advice about the type of habitat and how it should be managed, in response to the user stating which species were present. The pupils, therefore, had to think about which species were typically found in each habitat, how each habitat is managed and why these techniques were used. Building the model required selecting and structuring their knowledge.

The children worked in groups of 4 to build the diagram. The task of each group, which was explained to them by the teacher, was to choose one or more typical species and specify the habitat and its management. Within a group they took turns at the keyboard. Within each group at least one of the pupils had obtained some experience of using the Expert Builder tools, having worked on the previous model. When the diagram had been developed, some of the pupils went on to construct explanations for some of the clauses, this time working in pairs. This part of the work was not completed owing to lack of time.

The teacher checked on the pupils' progress in building the model from time to time intervening to help them in using the tools and deciding what to include.

6.3.4 Data collection

Four groups worked on producing the diagram and their work was observed and recorded. Audio recordings were made and notes were made of the pupils' interactions with the software. The tapes were subsequently transcribed and combined with the notes of interactions. At the end of the work the pupils were interviewed in pairs. The interview questions are listed in Appendix 3., The interview was intended to determine the following.

1 Pupils' perceptions of the purpose of the model.

2 Pupils' perceptions of how their model could be executed and used.

3 Pupils' views of the value of this and similar models.

4 Pupils' perceptions of how the program worked.

5 What the pupils thought they had learnt from building the models.

6 What the pupils thought about using the system.

In order to classify the interactions with the system and the pupils' and teacher's talk, networks were devised based on the technique of Bliss et al. (1983). This method was a way of categorising qualitative data in a way that showed the interdependencies between the categories. It involved examining the data and deciding on categories that would bring out the main characteristics of the data. Categories could be at different levels or might involve different criteria and the relationships between the categories were shown by a network diagram that derived its notation from systemic linguistics. The resulting network would be specific to the particular study and would not necessarily have any general applicability although it was hoped, in this case, that it could be developed or modified for a more detailed study of the same type. This method was chosen because it could capture, summarise and communicate the essential flavour of the talk and system interaction while being relatively straightforward to carry out, particularly with the use of a spreadsheet. The network used for system interaction (see Figure 6.3) was intended to indicate the relative amounts of use made of the different tools and techniques of the system and to identify the main problems encountered. Actions were scored each time there was a change in activity e.g. when a different tool was selected. This did not allow comparison of the time spent on the different processes but it did give an impression of which actions occur more frequently.

SYSTEM INTERACTION NETWORK

- Constructing
  - Tools
    - Box
    - Operators
    - Size
    - Hand
    - Bobbin
    - Scissors
    - Light bulb
    - Camera
    - A/O
    - Delete
    - Arrow
  - Text editing
  - Scrolling
- Testing
  - Question
  - Tick
  - Cross
- Problems
  - User interface
    - Tools
      - Box
      - Operators
      - Size
      - Hand
      - Bobbin
      - Scissors
      - Light bulb
      - Camera
      - A/O
      - Delete
      - Arrow
      - Question
      - Tick
      - Cross
    - Tool selection
      - Box
      - Operators
      - Size
      - Hand
      - Bobbin
      - Scissors
      - Light bulb
      - Camera
      - A/O
      - Delete
      - Arrow
      - Question
      - Tick
      - Cross
    - Scrolling
    - Editing
    - Layout
  - Metaphor
    - Text in clause
    - Linking
  - System errors
    - Stop
    - Clause box no text
    - Store rules

Figure 6.3 The network for analysing interaction with the software

The network used for analysing pupils' and the teacher's talk is shown in Figure 6.4. The talk was categorised by classifying each utterance. In some cases a remark was scored in more than one category. Again the network cannot give an accurate picture of the relative amounts of different talk in terms of time because utterances vary in length. In particular, points made by the teacher tended to be much more lengthy than those made by pupils. Nevertheless, it could convey the types of talk and give an approximate estimate of their relative amounts. The talk was classified initially into social and task related. The social talk was further subdivided into general gossip and personal comments, which were usually comments about individual failings.

Talk about using the system was classified in some detail so that it could be compared with the analysis of system interaction. Utterances were classified into questions, correct statements and incorrect statements. Problems with tools could then be identified. It was possible to determine to what extent the pupils were helping each other to learn the system and to what extent teacher intervention was needed. The network could give some indication of the relative amounts of subject and system related talk but talk about the subject matter was not further classified. There was no suitable method of categorising subject related talk that would be generally applicable since it was not predictable and was dependent on the situation and the pupils' prior knowledge.

The questions of interest concerning the subject related talk were:

1 Did the pupils discuss the subject matter?

2 Did building the model require or encourage the pupils to discuss the subject matter?

3 Did they need additional stimulus in order to discuss the subject matter?

4 Were inadequacies in the pupils knowledge and/or understanding revealed to them by building the model?

5 Did the pupils attempt to overcome these inadequacies?

It was decided that these questions could best be answered by directly viewing the transcript and providing relevant quotations.

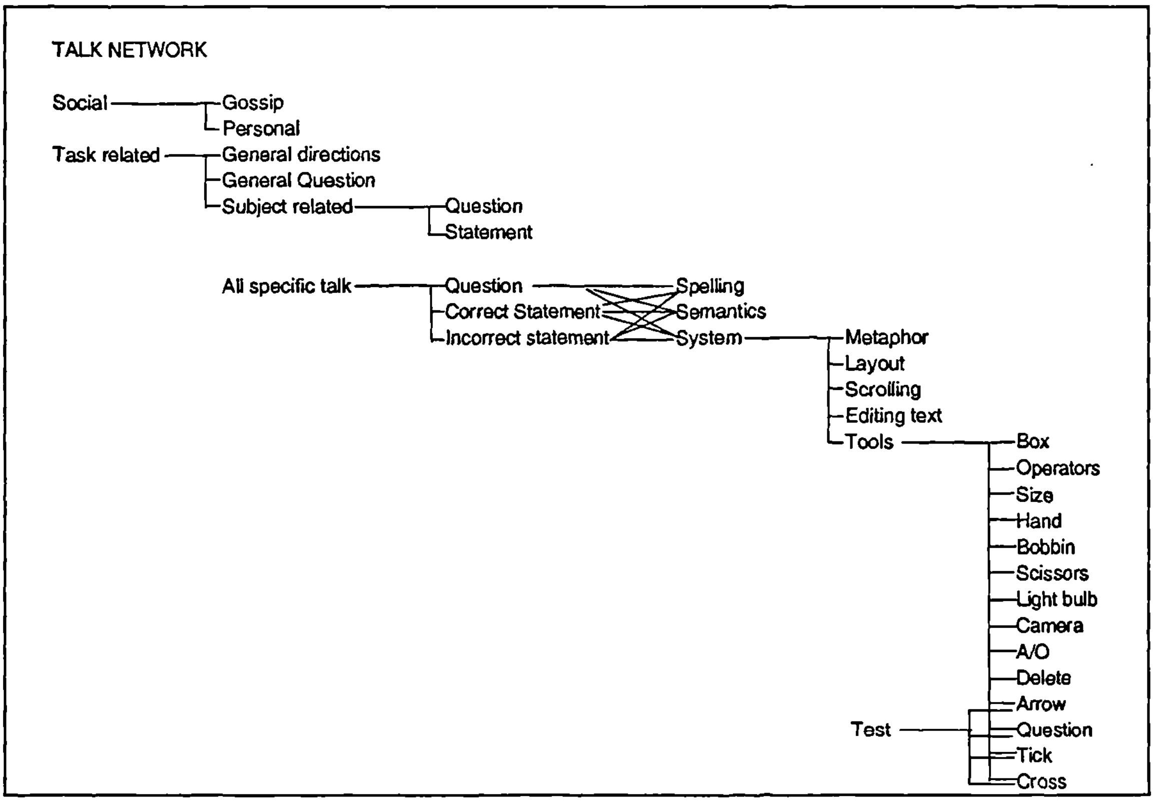

Figure 6.4 The network for analysing talk

6.3.5 Results and discussion of the pilot study

6.3.5.1 Interaction with the software

The method of categorisation used for the system interaction enabled a quick assessment and comparison between the groups to be made of the way the system was being used. Table 6.3 shows a summary of these results. The structure of the table is equivalent to the network shown in figure 6.3. The columns on the left hand side indicate the comparative total frequency of actions concerned with constructing the model, testing the model and encountering problems. Columns towards the right hand side show the more detailed breakdown of these categories. Results for each of the four groups (G1, G2, G3, G4) are shown together with the total (T) for all the groups.

Table 6.3 A summary of the results of network analysis of system interaction

	G1	G2	G3	G4	T		G1	G2	G3	G4	T		G1	G2	G3	G4	T		G1	G2	G3	G4	T
Constructing	46	21	44	27	138	Tools	41	14	39	25	119	Box	8	5	4	3	20						
												Operators	0	0	0	0	0						
												Size	1		7	0	8						
												Hand	1	4	15	8	28						
												Bobbin	15	4	9	9	37						
												Scissors	7	1	2	1	11						
												Light bulb	1	0	0	1	2						
												Camera	0	0	0	0	0						
												A/O	0	0	0	0	0						
												Delete	5	0	0	1	6						
												Arrow	3	0	2	2	7						
						Text editing	5	6	3	2	16												
						Scrolling	0	1	2	0	3												
Testing	9	8	0	7	24	Question	2	7	0	4	13												
						Tick	5	1	0	3	9												
						Cross	2	0	0	0	2												
Problems	17	14	13	6	50	User interface	14	11	13	6	44	Tools	5	7	9	5	26	Box	0	0	3	0	3
																		Operators	0	0	0	0	0
																		Size	0	1	0	0	1
																		Hand	1	2	0	0	3
																		Bobbin	3	4	6	5	18
																		Scissors	0	0	0	0	0
																		Light bulb	0	0	0	0	0
																		Camera	0	0	0	0	0
																		A/O	0	0	0	0	0
																		Delete	0	0	0	0	0
																		Arrow	0	0	0	0	0
																		Question	0	0	0	0	0
																		Tick	1	0	0	0	1
																		Cross	0	0	0	0	0
																							0
												Tool selection	2	0	1	1	4	Box	0	0	0	0	0
																		Operators	0	0	0	0	0
																		Size	0	0	1	0	1
																		Hand	2	0	0	1	3
																		Bobbin	0	0	0	0	0
																		Scissors	0	0	0	0	0
																		Light bulb	0	0	0	0	0
																		Camera	0	0	0	0	0
																		A/O	0	0	0	0	0
																		Delete	0	0	0	0	0
																		Arrow	0	0	0	0	0
																		Question	0	0	0	0	0
																		Tick	0	0	0	0	0
																		Cross	0	0	0	0	0
												Scrolling	2	0	0	0	2						
												Editing	5	4	3	0	12						
												Layout	0	0	0	0	0						
													0	0	0	0	0						
						Metaphor	2	0	0	0	2	Text in clause	1	0	0	0	1						
												Linking	1	0	0	0	1						
													0	0	0	0	0						
						System errors	1	3	0	0	4	Stop	0	0	0	0	0						
												Box no text	1	1	0	0	2						
												Save rules	0	2	0	0	2						

The construction tools used most frequently were the box, hand, and bobbin as would be expected. One group (G1) made more use of the scissors because they made a number of connections the wrong way round. Another group (G3) made much use of the hand because they were particularly concerned about the layout. Logical operators were not used at all in this model since the structure did not require them.

Problems were encountered in using the bobbin tool, text editing, using the scroll bars, interpreting error messages and laying out the diagram.

The use of the bobbin caused more problems than any other tool. Pupils found difficulty in positioning the thread in the right place. The system was subsequently improved so that users were given more feedback about when the hotspot of the cursor was over the box by the arrows changing colour. The hotspots themselves were also made more obvious.

The other main source of difficulty was the text editing. The text editor was the standard Windows editor. Pupils found difficulty in positioning the cursor. Some also tended to keep their finger on the backspace key therefore deleting more than they needed to. One or two pupils preferred to delete the whole box and start again when they made a mistake rather than using the text editor. Pupils were generally fairly slow using the keyboard. This problem with text editing was obviously not specific to this software since most word processors operated in a similar way. One limitation was that the size of text was set. Larger text might have been slightly easier to manipulate but would have increased problems of diagram layout.

Some difficulties were also encountered using the scroll bars, particularly when the scroll arrows were clicked inadvertently. There was considerable variability in the speed with which different pupils developed skills in using the interface. Most pupils had about 40 minutes using the system. In that time some became very adept at handling the mouse while others were still quite slow. It was felt that difficulties with the Windows features would be overcome with just a little more experience.

A few problems were encountered which generated error messages. The pupils were confused by these and were given help to find the cause. Two of these error messages, which were not totally necessary nor helpful, were eliminated. The only remaining one occurred when the model was run and there was a mistake on the diagram such as a box without text. This error message was essential and it was important for pupils to be able to find such errors although they needed some help to begin with. Ideally the system should highlight the cause of the error but this feature was not implemented.

One feature of the user interface which generated much discussion was laying out the diagram. One group, in particular (Group 3), had considerable discussion about the layout and used the hand a great deal to move boxes around. One of the problems was that when pupils were building models they needed to give considerable attention to the layout if the model was to be manageable and easy to manipulate. Only a limited number of boxes could be visible on the screen at a time and the connections could become confusing if the boxes are badly arranged. Much of the problem would be overcome if a larger work station type screen could be used. On the standard screen, the need for care in placing the boxes could only be overcome if some kind of grid were used. It was felt that this might reduce the flexibility of the system. The system supported several approaches to the construction of models. It was possible to start at the bottom of the page and work upwards from the premises or to start at the top and work down from the conclusions. Another approach was to place clauses randomly on the screen initially and then rearrange them as required. Pupils had control over the arrangement of their model and how it was presented on the screen. Inevitably they would spend time on the presentation but discussion of the layout would also help to clarify the purpose and functioning of the model. One of the reasons for a significant amount of moving of boxes while building one particular model was that a "bottom up" approach was used so they tended to run out of space at the top of the page. The model, of the Battle of Hastings, was built from the top downwards and required less rearrangement of the layout.

Other minor problems encountered with the user interface included forgetting which tool was used for moving and sizing, attempting to create a box on top of another or creating several overlapping boxes. However pupils quickly overcame these problems. Choosing the appropriate tool caused fewer problems than expected. Pupils very quickly learnt the functions of the tools even though some of the icons were slightly obscure, e.g. they had no difficulty in selecting the light bulb to create advice boxes.

The network proved useful for characterising system interaction, in particular identifying particular problems with the user interface. However the method required the complete concentration of the investigator so that it was not possible to observe other aspects.

One of the aims of the interview, described in Section 6.3.4 was to find out what pupils thought about using the system. Most pupils said that they had enjoyed using the software but several said they found some aspects of the interface difficult or awkward. The most common complaint was about the speed of the machine, which was a problem when using Windows on a floppy disk machine, e.g. one pupil said:

> *"It was a bit boring loading it and everything, and you have to wait and swapping disks around and everything"*

The majority of the pupils said that they found using the mouse difficult but they also agreed that they improved with practice e.g. one girl said she found using the mouse difficult but her friend added: "*At first its difficult but you get used to it*". Two other girls thought that "*thinking what button to use*" was difficult. They wanted to be able to use either button. This is a rather confusing feature of Windows, that there are two mouse buttons but only one is used. However most pupils became used to this quite quickly. One boy said that he didn't like using the bobbin and could not master its use. When pupils found some difficulty in manipulating the software, they became very frustrated if they could not overcome these problems quickly because they felt harassed by the others who kept giving them instructions. One boy, in particular, seemed to feel put out because the girls that he worked with were much more adept than he was at using the mouse.

This pilot study had shown that there were only a limited number of problems with the user interface. Several of these were expected to have been alleviated by slight improvements to the software as described above. Two issues that had been highlighted both by the questionnaire survey and by the pilot study were:

- the layout of the diagram - the difficulty of managing a diagram when not all the boxes were visible
- the "top to bottom" or "bottom to top" approach.

6.3.5.2 Classifying talk

The results of the network analysis of the talk are summarised in Table 6.4. Approximately 70% of all the task related talk was about the user interface. This was to be expected while pupils were still learning the system. The analysis of pupils' talk shows that only about 30% of all the task related talk was concerned with the subject matter. For example, in the extract from Group 1, consisting of two boys and a girl, shown below, the pupils start by considering the subject matter but structuring the model and using the interface quickly becomes their main concern.

Tom	*Come on, what did you say before?*
Stan	*Bluebells* (Tom places a box at top left and types in bluebells).
Tom	*Bluebells - yeh but what about them?*
Stan	*I don't know - we've got to do where they live.*
Tom	*Bluebells - they live in the woodland.*
Elaine	*No, the system has to tell you that doesn't it?*
Stan	*I don't know - I'm not a brain wave.*
Tom	*Ah* (typing "in the woodland" in the same box as bluebells).
Stan	*Whoops* (holding a key down so that text jumps around in the box).
Stan	*Press that* (the return key).
Ann	*Oh you've got to get rid of it.*
Elaine	*Get that little* (pointing to crossed box)
Elaine	*That's it.*
Tom	*I know how to do it.*
Stan	*Do you want that thing or not?* (Tom deletes the box and then gets the box tool again).
Tom	*Right where's the middle - its about there isn't it?* (places box on screen and changes to arrow tool).
Ann	*You don't have to change to the arrow.*
Tom	*Well I do.*
Tom	*Right, what shall we type?* (pause)

Stan	*Bluebells.*
Teacher	*Well, into that you are going to put the names of - Steven what did you say?*
Stan	*Bluebells.*
Tom	*Bluebells live in fields.*
Teacher	*But not all in the same box.*
Tom	*Ah so you put bluebells.*
Teacher	*Come on you girls, you're going to sit at the back there and do nothing. Before he does anything, is that the best place to put it ?* (box is in middle of screen).
Stan/Tom/Ann	*No.*
Stan	*Be better to put it in the corner.*
Teacher	*Remember how to move boxes.*
Tom	*Yeh.*
Teacher	*What icon do you want Tom?* (Tom clicks on the crossed box).
	No - well you could do that - but if you actually want to move a box you pick up the hand.
Tom	*Oh.*
Teacher	*Can you remember - because we did a lot of that in SENLAC?*
Tom	*Yeh - um - we want it about there.* (moving box to side of screen).
Stan	*Yeh.*
Ann	*We could move it a bit further.* (box still not at side of screen) (Tom tries to move box but lets go and then gives up and selects the delete tool).
Ann	*Click it.*
Tom	*Right.* (he deletes box).
Tom	*Want another box now.*
Ann	*Use the camera when you want to draw another box.* (Tom has selected the right box tool).
Tom	*No, that's for moving it.*
Elaine	*No, for copying it.*
Tom	*Is it?*
Ann	*Yes. Click somewhere.*
Tom	*Where?* (Ann points to top of side screen and Tom clicks to place the box and then selects arrow).
Tom	*Right, so ... bluebells ... it aint writing.* (Tom is typing but has not clicked in box - he only moved the cursor over the box). [giggles].
Tom	*Er ... um ... muffed this.*
Ann	*You have to click.*
Elaine	*Yeh, do it there* (pointing in box) *and click.*
Tom	*There.* (moving arrow over box)
Ann	*You have to click it or something.* (Tom clicks in box)
Elaine	*Yeh, that 's it, yeh, you've got it.*
Tom	*Oh yes.* (types BLUE). *Is bluebells one word?*
Ann	*Yeh.*
Tom	*Is it?*
Stan	*Bluebells is one word.*

Table 6.4 Summary of the results of the network analysis of the talk

Type of talk	Group 1	Teacher	Group 2	Teacher	Group 3	Teacher	Group 4	Teacher	Total pupils	Total teacher
Gossip	1	2			6				7	2
Personal	9				3				12	0
Gen directions				2		2		3	0	7
Gen Question	4	1		9	2	1	2		8	11
Subject Question	4	1	1	22	7	3	10	15	22	41
Subject Statement	14	1	25	2	13	2	25	10	77	15
Questions about using the system										
Spelling	8		1		1		1		11	0
Semantics				1			3		3	1
Metaphor	1	7	1	11		3		1	2	22
Layout	11	3		2	1		1		13	5
Scrolling									0	0
Editing text	1						2		3	0
Box			1	2	1				2	2
Operators		3							0	3
Size					2				2	0
Hand	1	3	1						2	3
Bobbin	1								1	0
Scissors		1	1						1	1
Light bulb		2							0	2
Camera	1								1	0
A/O									0	0
Delete									0	0
Arrow									0	0
Question	1		2	3					3	3
Tick									0	0
Cross			1						1	0
Correct statements about using the system										
Spelling	9	2			1				10	2
Semantics	1		1				2		4	0
Metaphor	9	2	14	13	6	3	9	3	38	21
Layout	14		2	4	14	3	7	7	37	14
Scrolling		1			3				3	1
Editing text	4	1		3	2		3	1	9	5
Box			1		7	1	2		10	1
Operators	2								2	0
Size				1	1	1		1	1	3
Hand	1		2	1	4	1	2	1	9	3
Bobbin	4		3	1	7	1	11	5	25	7
Scissors			1		1	1	1	1	3	2
Light bulb	3	2					1	1	4	3
Camera	4							1	4	1
A/O									0	0
Delete							1		1	0
Arrow	1								1	0
Question		4	7	7	2		4		13	11
Tick		5	1	1				1	1	7
Cross		1	1	2					1	3

(continued on next page)

Table 6.4 (Continued)

Type of talk	Group 1	Teacher	Group 2	Teacher	Group 3	Teacher	Group 4	Teacher	Total pupils	Total teacher
Incorrect statements about using the system										
Spelling	3								3	0
Semantics									0	0
Metaphor			2		2				4	0
Layout	6		1						7	0
Scrolling									0	0
Editing text	3				1				4	0
Box					1				1	0
Operators	6						1		7	0
Size									0	0
Hand					1				1	0
Bobbin									0	0
Scissors									0	0
Light bulb	2								2	0
Camera	3						2		5	0
A/O									0	0
Delete	1				1				2	0
Arrow									0	0
Question									0	0
Tick									0	0
Cross									0	0

In this study the talk related to the metaphor and the subject-related talk was only classified into statements and questions. In order for the network analysis to provide more than a very general view of the types of talk the analysis needed to be refined further. In this study it was felt that the relatively limited amount of subject-related talk did not merit further classification.

The "talk network" was useful for identifying the amount of and type of teacher intervention. It also revealed the degree to which pupils were helping each other to learn to use the software. All groups were given some help in using the system either when they asked for it or when they were perceived to be having difficulties. A considerable amount of teacher input was given concerning how to use the system. However the pupils made many correct statements about the use of the system and so they actually helped each other much more than they were helped by the teacher. Even in a group, that needed a great deal of help, pupils made as many correct statements about how to use the system as did the teacher. Pupils probably could have grasped using the system with less teacher intervention. They were quite prepared to try things and there were several occasions when pupils had found an alternative or even better way of doing something than that suggested by the teacher. One instance was where the teacher was suggesting using a separate advice box for each advice statement whereas the pupils had discovered that several advice statements could be connected to one advice box. Teacher intervention was usually intended to speed progress and prevent pupils from "wasting" time by using the system in an inefficient way. The talk network also revealed that a considerable amount of the talk was concerned with making use of the way the system works in order to make the model function correctly.

6.3.5.3 The modelling metaphor

In addition to the user interface, the other aspect of using the system which was of interest was the metaphor and approach used for modelling. For this model, the teacher had chosen a structure that only made use of some features of the system. The children were to start by thinking of indicator species which would be placed at the bottom of the screen and linked to their habitats. For each habitat, one or more clauses about its management would be added. The logical structure was therefore very simple and logical operators were not required. In order to create this model, it was necessary to understand how the environment would work. Pupils needed to understand that, for example, the presence of bluebells would imply a woodland habitat and that in turn would imply a certain type of management. They also needed to know that this line of reasoning must start from the bottom and work upwards. Group one initially constructed their diagram upside down. This was an understandable error since the previous model, of the battle of Senlac Hill, was constructed from the top downwards i.e. starting from the conclusions and then specifying the conditions. When their mistake had been explained they were able to correct it.

From the pupil interviews, it was clear that some pupils had a good understanding of how their model worked and how it was structured. The following extract from the interview with Ann and Elaine suggests that they have developed an adequate mental model which they can begin to apply to new situations.

Investigator	*Let's just imagine, you come up to the computer - can you just go through what would happen on the computer.*
Elaine	*Well you can look at the boxes to find out what we've written about and then you can ask it questions.*

Ann	*Yeh, and see what it says.*
Investigator	*What sort of questions?*
Elaine	*What's that thing in the hay meadow?*
Ann	*Um* ... [long pause]
Elaine	*Where do you find bluebells?'*
Ann	*Yeh, bluebells, that's it.*
Investigator	*OK. Good. And then what sort of answers would it give you?*
Elaine	*It would tell you about* [crackle, crackle - inaudible]
Investigator	*So, what do you think is the point of a system like that, not just this one, any system like that? Is it useful?*
Elaine	*Yeh, well, like the 1066 one what we done - it was changing the things that they used and everything and to find out who would win. And swapping the winning people around, say to make Harold win instead of William. And find out what Harold would have needed to win.*
Investigator	*What about you?* [Ann]
Ann	*Well, on the Battle of Hastings, it would tell you its proper name, where they slept and things like that and if they needed to sleep or else they wouldn't be awake when they did it and where they stayed, on the top of the hill and they came down.*
Investigator	*Can you think of any other things like that, where a system like this would be useful?*
Elaine	*You could do one about riding a bicycle, where to ride it and everything. And your car, how to get in it, how to drive it.*
Investigator	*Any other ideas Ann?*
Investigator	*OK. Do you think it would be useful to people out there in the world, not just in this classroom.*
Elaine	*Um ... hospitals, where to*
Ann	[muttering]
Investigator	*What was that Ann?*
Ann	*Where to find hospitals.*
Elaine	*And it would help doctors, with all their medicines and everything. And tell them, if you put it on, about all the medicines and how they work and everything. And what fever - what medicine you would need for a certain fever.*
Ann	*What things you need to make the medicines - what things you need.*

Ann and Elaine were able to explain what the user needed to do to use the system and what sort of answers were expected. They were also able to describe how the Battle of Hastings model could be used and the possibilities of asking what if -- questions. They gave four examples of other possible systems. They generally displayed a good understanding of the tasks that they had performed.

Carol and Cathy's answers suggest that they are much less clear than Ann and Elaine about the nature of the tasks in which they had been engaged:

Investigator	*OK. Good. Right, the idea is that you've built a system somebody else is going to use. Right? Can you explain, if somebody else is going to use it, what do they actually have to do. How do they use it?*
Cathy	*Use a mouse and a keyboard - tell them how to make the boxes and put all the words in.*

Investigator	*Right, that's what you had to do isn't it? You've now built this system which tells something about conservation and habitats haven't you?*
Cathy	*Yeh.*
Investigator	*So when they want to find out something about conservation and habitats, what do they actually do? How do they use the system that you actually built?*
Carol	*Read it.*
Investigator	*Yes, read it.*
Cathy	*And ask for information.*
Investigator	*How do they do that, how do they ask for information?*
Carol	*They find a piece of work.*
Investigator	*How do they find a piece of work?*
Carol	*By typing in the name of what its called.*
Investigator	*What sort of name?*
Carol	*Habitats.*
Investigator	*So, what do they type in?*
Carol	*Habitats.*
Investigator	*What does the computer tell them, then?*
Cathy	*About all the things in habitats.*
Carol	*About what goes in a pond.*
Cathy	*About what's in woodlands."*

These pupils were aware that the computer has stored their knowledge but they have very little idea of how it is structured or how it could be used. They seem to have an upside-down model of how their systems would work. Other pupil's answers showed perceptions between these two extremes.

In order to make good use of a modelling system such as Expert Builder, pupils need to develop their own mental models of the modelling metaphor. The interview was not sufficiently detailed to determine how much of the logical structure and inference the pupils had understood, but the answers given by Ann and Elaine showed that they had realised that the knowledge that the user puts into the system is stored and can then be presented by the system in a different form but with the same content:

Investigator	*OK. Now, the actual program that you used to build the system, do you know how it works?*
Elaine	*It will only put what you write on it.*
Ann	*It will store things in it and then when you come back to it, it will tell you all about it so it all comes back to you.*
Elaine	*But it wouldn't tell you about, er moorlands, if you hadn't wrote about them.*

Carol and Cathy's answers suggest that their understanding of how the system works is less clear than that of Elaine and Ann:

Cathy	*Its telling you if they're right, the red boxes, and blue if they're wrong.*

Investigator	*How does it know to tell you that? How does the computer know?*
Cathy	*You get a tick or a cross and then you get the question mark and you put it to the answer and it'll show up red or blue if its wrong or right.*
Investigator	*How does the computer know whether its wrong or right Carol?*
Carol	*By showing red if its right and blue if its wrong.*
Investigator	*How does it know to show it red or blue?*
Carol	*Well, we typed it in.*

It is difficult to determine, from this conversation, the level of their understanding since these pupils were also limited by their ability to verbalise their ideas. They also had limited self confidence and tended to have a rather low opinion of themselves as learners, from my observations, which were confirmed by the teacher.

The interview questions, discussed in Section 6.3.4, were intended to reveal pupils' general perceptions of their computer models and the way the system worked, rather than revealing any detailed view of pupils' mental models. Several of the pupils gave good descriptions of their models especially considering that there had been a gap of about two to three weeks since they had been working on the models.

The metaphor and functioning of the system proved to be adequate for this model. The facility to provide explanations of clauses was used to only a very limited extent owing to lack of time but the teacher felt it to be particularly useful for giving detailed information about conservation management techniques. In subsequent work on other topics, described in Chapter 8, the teacher focused more on using the explanations facility and encouraging the children to provide good clear explanations of their clauses.

The Senlac Hill model actually made more use of the rule structure since it required logical operators. The teacher felt that the need to define specifically the possible combinations of 2 out of 3 clauses was a valuable exercise but secondary school teachers have commented that it would be useful if the system could automatically work out combinations of 2 out of 3 or 3 out of 8 etc.

6.3.5.4 Spelling and semantics

Approximately 8% of task related talk concerned spelling and semantics. Pupils made considerable effort to spell correctly and to make sure that their clauses were clear.

6.3.5.5 Subject Matter

Figure 6.5 shows the completed model and Table 6.5 lists the clauses and associated explanations. The model was quite limited although it represented about 4 hours of work at the computer as well as other background and research work. The analysis of pupils' talk showed that only about 30% of all the task related talk was concerned with the subject matter. Therefore during this period of model building, pupils were having to expend more effort on learning to use the system than on considering the subject matter. This was not unproductive because they were developing manipulative, social and problem solving skills. However it was hoped that the proportion of talk about the subject matter would increase with experience in using the system. It was clear that to gain full benefit, considerable time needed to be invested in learning the system. This could be problematic given the limited availability of equipment in most schools.

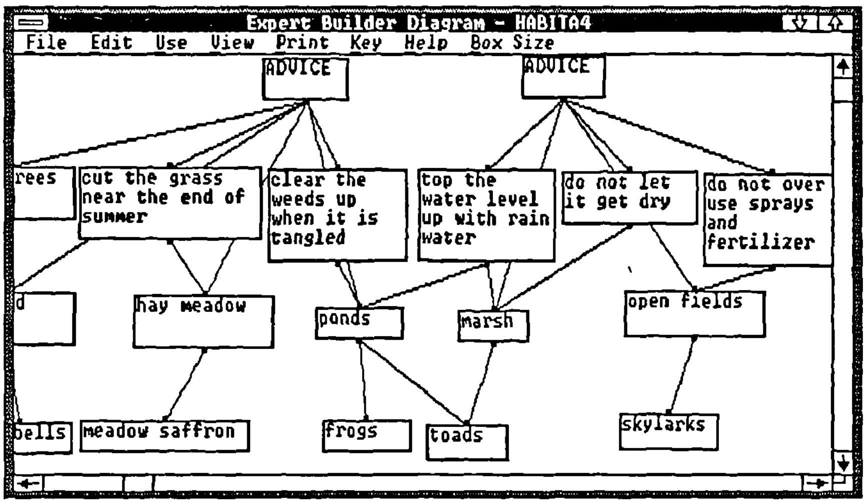

Figure 6.5 The completed model about habitats

The short session in which two pupils started to write explanations focused more heavily on the subject matter. While the pupils were using this facility, they were only having to type in information rather than having to consider the modelling metaphor. The proportion of time spent discussing the subject matter therefore increased.

However it was the structure of the model which was providing the focus for the discussion. Although this structure could have been provided by the teacher, the "ownership" of the model may be an important motivating factor.

Table 6.5 Clauses and associated explanations for the model about habitats.

ADVICE
bluebells
[Bluebells grow in a woodland. They are shaded by oak and ash trees. The bluebells store food in their bulbs. Then they grow their leaves and flowers, then they die. They have to do this before the trees grow their leaves because they would not get enough sunlight after the trees have done this. Bluebells also like the woodland area because it is damp.]
clear the weeds up when it is tangled
cut the grass near the end of summer
[The grass must be cut once a year because the plants that grow in hay meadows do not like their tops cut off every week. These plants send up flowers in early Summer and the seeds scatter and then germinate. The hay meadow plants have very long stems. After the grass has been cut it has to be taken away so that the new plants can grow. If the grass wasn't taken away the soil would get too much nutrients. If the soil got too much nutrients the grass would take over the hay meadow. The other species would die.
do not let it get dry]
do not over use sprays and fertilizer
frogs
hay meadow
marsh
meadow saffron
open fields
plant trees
ponds
skylarks
toads
top the water level up with rain water
woodland

Despite the relatively low proportion of subject related talk the main modelling task of constructing the diagram did encourage the pupils to think about the subject matter. They asked a number of questions about the subject matter which showed that they were trying to include appropriate knowledge, e.g.

> *"Then you want the management of fields. So er .. like the pond's management - keep the water in.*
> *Come on what else do you have to do to manage the things?*
> *What do you have to do to the fields?*

You've got to wait for the grass to grow".

Unfortunately, when pupils realised that they did not have the knowledge they needed they tended either to move on to something else or to ask the teacher. The teacher had hoped that pupils would have acquired sufficient knowledge from class discussions and other related work but the pupils seemed unable to recall or find this information. The notes which pupils had made in their notebooks were very limited and inadequate. When the teacher intervened to prompt the pupils they were able to recall some relevant knowledge e.g.:

Teacher	*What are you going to put in there?*
Pupil	*Management for open fields.*
Pupil	*Do not build houses.*
Teacher	*What sort of person owns the field?*
Pupil	*Farmer.*
Teacher	*Yes.*
Pupil	*Do not use it as farmland.*
Teacher	*Susan you're not listening. The open fields ARE farmland. What do you think farmers shouldn't do to their farmland?*
Pupil	*Pollute it by using chemicals"*

On several occasions the teacher suggested that they should look something up in a book. However, the pupils were not keen to leave the computer. This was probably because the use of the computer for model building was still seen as a novelty. They did not want to miss out even though in a group of 4 it would have been quite feasible for 2 of them to be researching information while the other 2 were building the model. The pupils were used to using reference books for their other work but in this situation were unable to organise themselves. The provision of suitable resource material is very important for this sort of work and it would have been quite difficult for pupils to obtain the information they needed from the books available.

6.3.5.6 Pupils' views of what they had learned

The pupils themselves, when interviewed, all said that they preferred this way of working to other methods. This suggests that there is some motivating effect although this may have been just the novelty value. They felt that they were learning and finding out more information than they might in other classroom situations. Susan's views are fairly typical but she is more articulate than some:

Investigator	*Do you think you've learnt anything by using the program?*
Susan	*Well, I suppose its taught me a bit more about computers. Different things on the keyboard and which things to use on the mouse and different parts of it.*
Investigator	*Do you think you learnt anything by building the system about conservation.*
Susan	*Well, by building it then I had to research and I suppose I was doing extra research that I wouldn't have done before. Its making me find out more, that I wouldn't normally do.*
Investigator	*Good. What did you think of the program? Any comments on it?*
Susan	*Well, I thought it was an interesting, a good system, to do things on it and it was fun to do, because it was easier in a group because different people have different ideas on it. And we tried it, and then with the advice box, that helps you, because the computer's already got information stored up so it helps you to put more information in.*

6.4 Conclusions from the pilot study

In this investigation Expert Builder was used in two contrasting ways. The first model made use of the logical structure. It concentrated on combinations of factors that led to one of only two possible outcomes in a particular situation. The second used only simple rules with no logical operators and was partly a classification system for habitats but also led to a second level of conclusions. This was an indication of the great flexibility of the environment. It enabled two very different types of model to be built and the teacher was able to envisage ways of using the environment in both of the topics that he was covering at that time. The two very different approaches to using Expert Builder were probably not very helpful in enabling pupils to understand the modelling metaphor. It would have been easier for them if they had been able, in the second activity, to build on what they had learnt about the modelling metaphor rather than seeing a very different use of it. The teaching and learning methods adopted by this teacher were similar to the "legitimate peripheral participation" process (Lave and Wenger 1991), which is discussed in Chapter 3 Section 3.8.3. The teacher decided on the problem and on the basic structure of the model but he showed children how he designed it and explained to them how it was working. Groups of children then participated in building and testing parts of the model. The discussions they engaged in with each other and with the teacher were important in learning how to use the software.

The possible classroom uses of Expert Builder were very varied and any evaluation, in a classroom setting would be dependent on and be inextricable from other aspects of the classroom environment. In this study there was little opportunity for pupils to use their own ideas about how to structure the model. The detailed study, discussed in Chapters 7 and 8, enabled more of this different style of working.

This class was selected for a detailed analysis because they were expected to spend considerably more time on the computer than other groups. However, the limited time on the system was still an obstacle to achieving the full benefits of this work. Each individual pupil spent no more than about 40 minutes actually using the software. It is possible that such benefits will not be accessible until computers become more freely available in classrooms.

This pilot study showed that there were only a limited number of problems with the user interface, several of which were expected to have been alleviated by slight improvements to the software as described earlier.

The method of categorisation used for the system interaction network enabled a quick assessment and comparison between the groups of the way the system was being used. This was useful for identifying problems with the user interface. However the method required complete concentration so that it was not possible to observe other aspects. Therefore it was decided that, in the detailed study, this technique would only be used sparingly in order to allow a wider range of observations to be made. This was acceptable in the light of the evidence that use of the interface was not a barrier to modelling in this environment,

The majority of the pupil talk (70%) was about using the system. The teacher gave the pupils a lot of help in using the system but the pupils also helped each other a great deal in learning how to use the system which seemed to be important. There was not enough talk about the use of the metaphor to know if it also helped pupils to develop mental models of the metaphor because the teacher had made the decisions about how to make use of the metaphor.

The "talk network" was useful for identifying the amount of and type of teacher intervention and the degree to which pupils were interacting and helping each other to learn to use the software. The network needed to be developed further in order to characterise the types of verbal interaction. This was not considered to be worthwhile in this pilot study because the amount of talk relating to the use of the metaphor and the subject matter was quite limited. However in the more detailed study, described in Chapters 7 and 8, the network was refined further to identify the types of questions and responses that the pupils were using. This was intended to clarify aspects of the modelling process and the group interaction. It was only possible to refine the network when transcripts of the main study were examined because the method of network analysis was intended to characterise the particular subject matter under consideration and the talk was different in nature in each study.

An important aspect of using Expert Builder has been identified as developing a mental model of the modelling metaphor. This pilot study suggested that pupils' understanding of how the system works was quite varied. A major goal of further work, described in Chapters 7 and 8, was to attempt to reveal the extent of this understanding in greater detail by carrying out a longer term study and making use of structured tests of competence in using the software. The longer term study also focused on the problems in using the software suggested by the pilot study. This pilot study was carried out in the normal classroom situation and confirmed that Expert Builder could be used in this setting. It was decided that the main study should also be classroom based in order to extend knowledge of the potential for qualitative modelling in this setting.

Chapter 7 Classroom Evaluation - Methods and Rationale

The initial evaluation, described in Chapter 6, showed that the possible classroom uses of Expert Builder were very varied, suggesting that a classroom evaluation would need to be a long term study. This would allow the pupils sufficient access to the software and would enable the computer based modelling work to be fully integrated into the normal classroom environment. In this chapter the design of the detailed study, which investigated the classroom use of qualitative modelling, is discussed and the methods and rationale are described.

The main part of the study focused on qualitative modelling integrated within the normal curriculum and classroom setting. Following this work a structured test was devised to try to identify pupils' mental models of the software. In Chapter 5 the importance of pupils developing a mental model of the modelling metaphor was discussed. The pilot study of classroom use of the software, discussed in Chapter 6, suggested that pupils' perceptions of how the system works were quite heterogeneous. Therefore the structured test was devised to reveal the extent of their understanding of how the system works.

7.1 The main study

The main study was classroom based in order to extend knowledge of the potential for qualitative modelling within the curriculum and in normal classrooms.

The main questions addressed in the main study were:

1. How can Expert Builder be used within the normal primary school curriculum?

2. What kinds of structure do the pupils attempt to create and to what extent does Expert Builder support them in these attempts?

3. To what extent do pupils develop a mental model of the modelling metaphor which will enable them to design their own models?

4. What problems do pupils encounter when they try to make use of the modelling metaphor?

5. What skills and processes are involved in computer based modelling?

The answers to questions 1 to 4 are discussed in Chapter 8 and summarised in Section 8.4. The answer to question 5 is discussed in Chapter 9

7.2 Methods and rationale

The study was conducted in three primary schools which served semi-rural communities. In Schools A and B the modelling work was planned and organised by the teachers to be part of their normal classroom activities. They were both experienced teachers who had previously taken part in a research project using an expert system shell. The teacher in School A had also worked on the pilot study so he was now fairly familiar with the features of Expert Builder. The teachers had both volunteered to take part in the study after they had joined the Modus Club. They had spent some time using Expert Builder and had decided that there were opportunities to use this software in their classrooms. They were shown the main features of the software but they were not introduced to all its facilities. They had also spent some time working through the Expert Builder User Guide. They agreed to look for opportunities to incorporate modelling with Expert Builder into their normal classroom work during the following school year. The progress of the work in Schools A and B was monitored by visits to the school on about a fortnightly basis whenever they were pursuing activities that involved using Expert Builder. In all, five hours of computer work was observed in School A and eight hours in School B.

School C had been selected to take part in a Modus Project video. This selection was made for practical reasons and the school had not previously been involved with work on the Modus Project. Preparation for filming of the video involved me working with groups of children from one of the classes to develop models in Expert Builder. This work was extended in order to enable it to contribute to this evaluation study. In this school, some of the pupils from year 6 (aged 10 and 11) developed models alongside their classroom work. This took place in the Summer term during five day visits to the school over a period of five weeks. The class teacher did not participate in the work. Although she was very keen for the pupils to take part, she appeared to be apprehensive about using the computer herself therefore I acted as both tutor and observer in this school.

During the pilot study the pupils had had little opportunity to design and structure the models themselves since the teacher had provided them with the basic structure. It was felt that it would be essential in the main study for the teacher to provide the structure in the earlier stages. It was hoped that as the pupils became more familiar with the software, they might gradually be able to take a larger role in the design and structuring of the models. The study was conducted within a typical classroom context, in order to address question 1. In order to address questions 3 and 4 above, the pupils would be tested following their work with Expert Builder in the classroom. Questions 1, 2, 4 and 5 would be investigated by observing and recording pupils during their work with Expert Builder particularly when they had spent more time using Expert Builder and were likely to have developed more expertise.

The intention was to try to record the progress of each modelling activity, including any preliminary work, how the modelling task was introduced by the teacher and how the pupils carried out the tasks. In Schools A and B approximately 25% of the modelling work was observed so some of the information had to be obtained by talking to the teachers. When the schools were visited, groups were observed and audio recordings were made wherever it was thought to be appropriate. During some of the earlier visits it was necessary for the author to provide some advice to the teachers in using the software or technical help in setting up the computers. It was also necessary to provide help to the pupils. As far as possible the author acted purely as observer in Schools A and B but where there were problems with software bugs or the pupils were making mistakes that were clearly obstructing their progress, the author intervened to provide help. On some occasions the teachers asked me to help pupils with particular problems that they were unsure about.

The network and checklist that had been designed, during the pilot study, to capture and analyse system interaction, (see Chapter 6, Section 6.4.4) were used on two occasions; once when the pupils were still learning how to use the software and later with pupils who were much more familiar with the software. The two samples enabled comparisons to be made and the second sample, in particular, enabled differences in the way the software was used by pupils with more experience to be identified. The possibility of using some kind of "dribble file" to record interaction with the software was considered but this would have meant adapting the software and possibly slowing it down. It would then have recorded every mouse click etc. whereas the real need was to record the modelling process and to note any particular problems. This could be achieved by observing and note taking. The models made by the pupils were saved at the end of each session and usually kept by the teachers so that it was possible to see how progress had been made. When sessions were observed, the investigator saved versions of the model when appropriate. In addition, the investigator observed and sketched particular parts of the models since it was not always possible or desirable to stop pupils and save the models.

It was decided to use audio recording rather than video for several reasons. First it was less intrusive for the pupils being recorded. Secondly, the physical conditions in the schools were rather cramped and it would have been difficult to position the video camera where it would not have been in the way of other children without moving the computers from their normal positions. Thirdly it was felt that audio tapes and observation would enable all the interaction to be recorded. The main aim of recording the pupil talk was to try to characterise the pupil - pupil interaction, while they were modelling, particularly when they had reached the stage of being fairly familiar with the software and were able to concentrate on the modelling. The audio tapes were transcribed. Some of the talk during the later stages of the modelling activities, where pupils were more familiar with the software, was analysed. The network analysis technique of Bliss et al. (1987) that had been attempted during the pilot study (See Chapter 6, Section 6.4.4) was used. In this case the network structure was revised

(Figure 7.1) with a view to capturing the types of talk so that it might be possible to determine whether and how pupils were learning from each other.

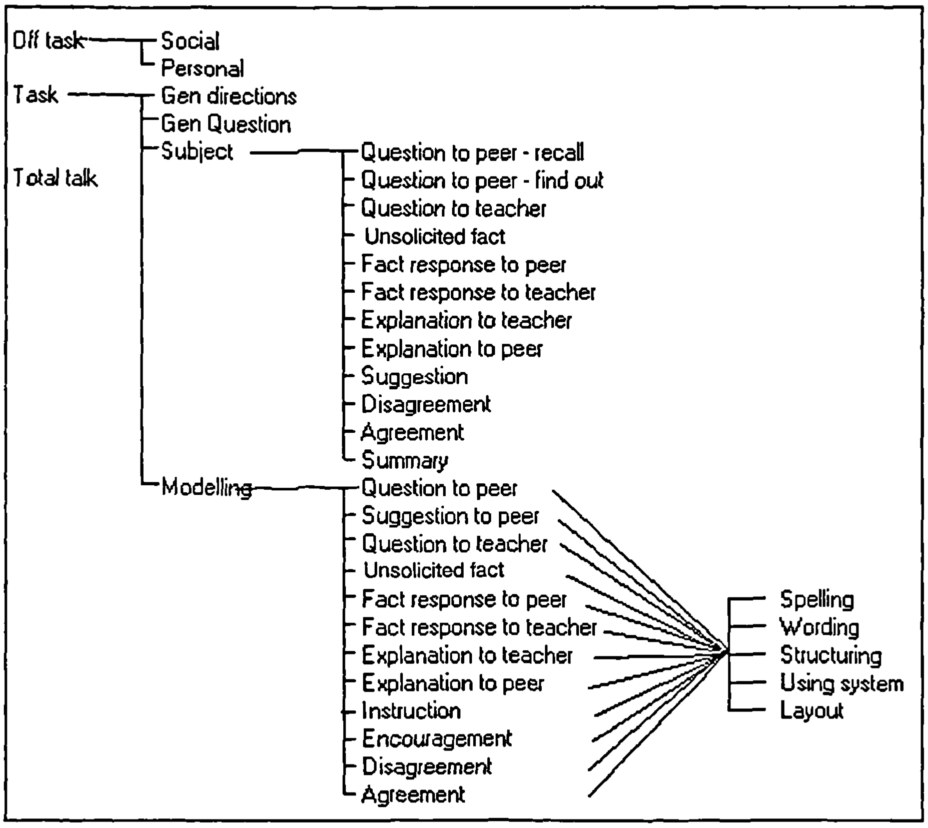

Figure 7.1 The revised network for analysing pupil talk

Using this new network each utterance was classified as either being about modelling or about the subject matter. It was then further classified to show the type of utterance, e.g. question to a peer, explanation to peer. In some cases a remark was scored in more than one category. The network cannot give an accurate picture of the relative times spent on of different talk because utterances vary in length. But it could convey the types of talk and give an approximate estimate of their relative amounts.

7.3 Outline of the study

7.3.1 School A

In this school the class participating in the study was a small one. It consisted of eleven year 6 pupils (aged 10 to 11) with some year 5 pupils (aged 9 to 10). Only the year 6 pupils participated in the work with Expert Builder. The teacher regarded this group as ranging from a little above average to fairly well below average in academic ability.

There was one computer in the classroom, a Nimbus 186 with a Winchester disk drive, and it was used by pupils working in groups of 2, 3 or 4. The computer had Windows 2 running in 1MB of RAM so that Expert Builder performed adequately. The teacher organised its use so that pupils took turns to use it for particular purposes when appropriate for their work. It was intended that modelling with Expert Builder should be a normal part of the classroom work and the computer was also used for other activities such as word processing and graphics work. The teacher made use of Expert Builder when he felt that an aspect of the topic on which they were working was appropriate for modelling with Expert Builder. He outlined the programme of work to the author, including how he expected to use Expert Builder and the author confirmed that the activities appeared to be feasible. During the first part of the Autumn term the class was working on a topic about holidays as part of a study of the Far East. The teacher introduced Expert Builder by working with small groups of pupils to construct a model about where to go for a holiday. Three groups of pupils went on to build a further model about selecting a hotel. This work took place over about three weeks. Three groups were each observed on two days. During the second part of the Autumn term the class topic was energy and several groups built models on conserving energy in the home. This work took place over five weeks and was observed on two days. During the early part of the Spring term the class was studying developments of technologies. The teacher used 'Connections: a history of technology.' by James Burke as stimulus material. The class used Expert Builder to develop a system based on this book. Visits were made only at the end of this work when the pupils demonstrated the model to the author. Later in the Spring term, the class was developing a database and Expert Builder was not used during this period.

7.3.2 School B

In this school the class of about 30 contained both year 5 pupils (aged 9 to 10) and year 6 pupils (aged 10 to 11). Seven of the year 6 and four of the year 5 pupils took part in the study. The teacher regarded the pupils as ranging in ability from well above to fairly well below average.

There was one computer available to the class. It was situated in a work area outside the main classroom and it was used by pupils working in groups of 2 or 3. The computer was a Nimbus PC1 with 1MB of RAM i.e. a 186 with one floppy drive. Disks were provided to autoboot the machine so that Windows 2 was loaded and then the Windows disc could be removed and the Expert Builder disk inserted into the drive. The performance of Windows, in this situation, was rather poor and the software ran rather slowly. The teacher organised use of the computer in a similar way to School A so that pupils took turns to use it for particular purposes whenever its use was appropriate for their work. It was intended that modelling with Expert Builder should be a normal part of the classroom work and the computer was also used for other activities such as word processing and graphics work. The teacher made use of Expert Builder when he felt that an aspect of the topic on which they were working was appropriate for modelling with Expert Builder and he felt able to devote time to preparing the topic. As in School A, the teacher discussed his intentions with the author and again there was no need to suggest modifications to his plans. During the second part of the Autumn term the class was working on a topic about communications and three groups of pupils built models about selecting a method of communication. Expert Builder was not used during the Spring term as the teacher and the class had other commitments but in the Summer term, when the class were working on a topic about the skeleton and bones, three groups built models about identifying bones. In each case, the teacher decided on the structure for the model and introduced a small group of pupils to the software by showing them some examples of models and how they worked. He then started them off with their models by working with them to produce the first few rules. The pupils then carried on building the model, following a similar pattern and the teacher gave them help from time to time as he went around checking on the progress of each group.

7.3.3 School C

The class was working on a topic about rock formation, volcanoes and earthquakes and the pupils who worked with Expert Builder built models to identify rocks. There was a Nimbus 186 computer in the classroom, which from the comments by pupils, was probably used very little except for playing games during the lunch hours. There was also a BBC Master which seemed to be used very little. For the study two extra computers were borrowed so that three pairs of pupils could work for an hour at a time. Therefore 12 pupils were involved and they ranged in ability from well above to well below average. Following the work on rocks four of the groups attempted Exercise 3 of the "test of competency", an open-ended modelling activity, which is described in Section 7.4.3. Their progress was observed and notes were made but no tape recording was made. During a further day pupils were given the opportunity, on a voluntary basis, to build models of their own choice. Throughout this work, several groups were working at any one time. At the start the intention had been to tape record some of the groups but this proved to be impossible because the groups were in close proximity and the work was interrupted fairly frequently so these attempts were abandoned.

7.4 Test of competency

This test was devised in order to try to measure the level of competence in using Expert Builder, which the pupils had reached by the end of the classroom work and to identify the difficulties which they experienced. The test was designed primarily for use in Schools A and B where each individual pupil had spent between 3 and 10 hours using the software with one or two other pupils. This was quite a limited amount of time for a sophisticated piece of generic software but was about what could be expected realistically given the availability of computers. The aims of the test were:

- to determine how well pupils are able to use the tools in the system
- to elucidate the nature of pupils' mental models of how the system works
- to determine how well pupils can use the system metaphor to write models
- to identify any difficulties pupils have with understanding and making use of the system
- to determine the kinds of reasoning pupils use with and without Expert Builder.

The test is included in Appendix 4. There were three exercises. The first two exercises contained 16 short tasks and Exercise 3 consisted of one open-ended task.

7.4.1 Exercise 1

In order to be able to make use of the modelling environment, at the simplest level, it is necessary to understand the basic structure of a rule as it is represented on the diagram and how the inference mechanism would use the rule. The simplest adequate mental model would enable a pupil to predict how the system would behave when run with a very simple rule. Another requirement for success in modelling, which was suggested by observations of pupils during the classroom study, was to be able to identify similarities between tasks. Teachers started pupils on a modelling exercise by helping them to create a few rules and then encouraging them to use the same basic structure for further similar rules. Discussions with expert modellers from research and industry, during several seminars, suggested that part of their approach when tackling a new problem, was to look for similar behaviour patterns to other problems that they had encountered in order to determine what techniques to apply. Observations, which are discussed in Chapter 8, showed that the pupils who were more successful had applied the techniques shown by the teacher and then gradually experimented with their own ideas. Some pupils failed to make use of the rule patterns which they had been shown. This exercise, which contained 11 short tasks, was therefore designed to determine:

- how easily pupils were able to manipulate the user interface and to identify any problems with the interface
- whether pupils had developed mental models of the basic rule structure contained in the diagram and how it was used by the system
- whether pupils were able to create a simple rule by following a pattern.

In the exercise the pupil was presented with a simple model which advises on whether someone could keep a goldfish as a pet (see Figure 7.2). The pupil was given a series of questions which involved predicting the model's behaviour and modifying the model.

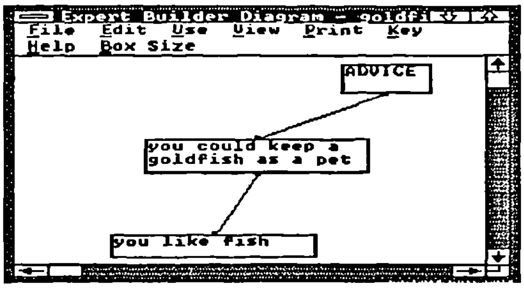

Figure 7.2 The simple model used in Exercise 1

7.4.2 Exercise 2

This was concerned with the use of the logical operators and was intended to determine whether pupils understood their meanings in the diagram. The pupils had made little use of these during their work, the teachers had encouraged them either to use very simple rules with no logical operators or to use AND, and it seemed unlikely that they had gained much understanding of the use of the operators. The exercise was originally designed to be very short. Its purpose was to determine how many pupils had noted the difference between and the significance of AND and OR on the diagram. However the exercise was extended and more explanations were asked for when the first two pupils showed greater than expected understanding and some interesting problems were noted. The exercise required pupils to tick one or more of the boxes in order for the rule to fire. They were encouraged to tick the minimum number of boxes because ticking all the boxes would also result in the rule firing as OR was inclusive. This was felt to be useful in this instance because pupils could be praised for achieving success whilst being encouraged to seek further answers by ticking fewer boxes. In the first part of the exercise the diagrams were based on rules about keeping pets (see Figure 7.3. If the pupil achieved a good answer it could be due to either:

correct interpretation of the diagram

or correct reasoning on the subject matter

A pupil who did not achieve the best answer may have:

misinterpreted the diagram

or used poor reasoning on the subject matter.

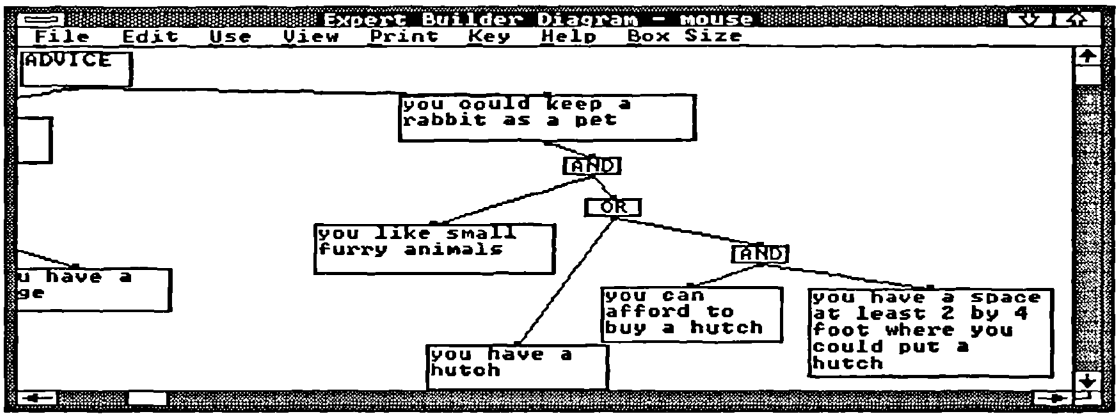

Figure 7.3 One of the rule structures used in Exercise 2

The pupils were asked to explain why they had given a particular answer. Generally their explanations were incomplete and not very coherent but no attempt was made to prompt them into being precise. Their answers were used to determine whether:

1 they attempted to justify their answer in terms of the subject matter

2 they attempted to justify their answer in terms of the logical structure as presented on the diagram

3 they had guessed.

If a pupil's explanation, for a good answer, fitted into category 1 it could mean that they were using their own reasoning rather than using the rules presented by the system or that they were explaining the system's rules. If the pupil explained an answer using her/his own logic A, when it was inconsistent with the logic used in the model this would suggest that the pupil was ignoring or being distracted from the logic in the model by the subject matter.

In Task 12, where pupils were required to tick both boxes in order for the rule to fire, they were questioned to determine whether they understood the difference between AND and OR by changing the AND to OR and asking them to say what they would need to tick now. In order to avoid this being a pure guess they were asked to explain and were only scored as having achieved this correctly if their explanation indicated that they recognised the difference between the meaning of AND and OR. At this point, of course, their attention was being specifically drawn to the logical operator.

In task 13, the pupil's answer was recorded on the diagram. It was also noted whether their explanation was related to the subject matter or to the logical structure of the diagram or was just a guess.

Tasks 14, 15 and 16 used diagrams where the clause boxes contained letters rather than meaningful clauses (see Figure 7.4). In each task the pupil was asked to explain her/his answer and an attempt was made to determine whether the answer displayed understanding of the logical structure or whether the pupil was guessing. It had been expected that few pupils would be able to deal with the logic in this abstract way and where pupils were obviously confused they were not pressed to explain their answers and in some cases the tasks were not completed. Each pupil was encouraged to look for better answers where they didn't immediately see the best solution. Some explanations were given to the pupils where their own explanations showed confusion and where it was felt that they might be able to learn from a further explanation.

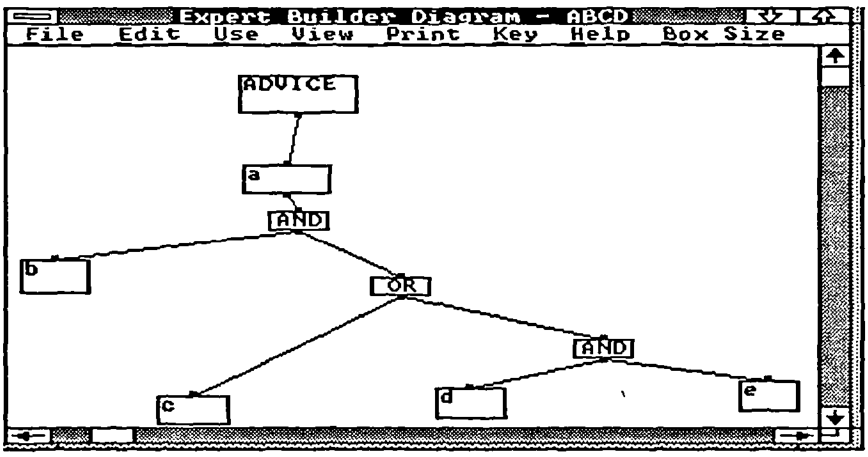

Figure 7.4 The model structure used for task 14

The pupils' previous experience with Expert Builder and the amount of help they had been given was obviously variable. Working through exercises 1 and 2 enabled some further learning to take place and gave some preparation for Exercise 3.

7.4.3 Exercise 3

This was intended:

- to determine to what extent pupils could make use of the modelling environment to construct their own models
- to identify the problems which pupils have in making use of the modelling metaphor
- to determine the kinds of structures which pupils try to represent in their models
- to determine the kinds of discussion and reasoning facilitated by the model building exercise.

During all the exercises that pupils had previously attempted with Expert Builder they had been given a great deal of help in structuring their model. In this exercise the pupils had to decide for themselves how to structure the model. They were given help only if they were clearly floundering and were unable to make progress and this is documented in the results. In the first part of the exercise one pupil was asked to imagine that (s)he was the visitor from another planet and the other pupil was the expert giving advice. This was intended to encourage the pupils to think about the situation and to determine to what extent they could grasp the problem and structure their ideas before embarking on constructing the computer model. This exercise was used because the subject matter was general knowledge which all the pupils could be expected to possess and therefore there would be no need for prior research. It was also a situation which they were unlikely to have thought about previously so it would involve them in applying their knowledge to a new situation. The talk during exercise 3 was recorded and their interactions with the system were noted.

The test was conducted with the 22 pupils who had worked with Expert Builder over the two terms. In some cases there had been a lapse of several weeks between using the system and doing the test. Two groups of the pupils from School C also undertook Exercise 3. The test was conducted by giving oral instructions. It was explained to the pupils that they were taking part in experimental work to test this particular piece of software and that they were not being assessed. The tasks were devised so that all pupils could feel that they had achieved a high level of success. In most cases there were several ways of achieving a particular goal. If a pupil was unable to carry out a particular task (s)he was generally given assistance to complete it, except where this was felt inappropriate as explained earlier. This experience enabled some pupils to fill gaps in their understanding and expertise and might have assisted them in subsequent tasks. This was felt to be desirable because pupils had not been systematically trained in how to use the software. This test was determining what they had picked up through their work with the system. This work could be considered to be typical of how such a package could be used in a normal school classroom given the current level of provision of hardware.

The results of the classroom trials and the test of competency are presented and discussed in Chapter 8.

Chapter 8 Results of the Classroom Trials

The methods and rationale for this study are described in Chapter 7. The study took place in three primary schools over one school year. Teachers developed the modelling work alongside their normal classroom work. The first part of this chapter is a detailed description of childrens' modelling work. These results are then discussed with reference to specific aspects of the modelling process. Pupils' interactions with each other and with the software are then analysed and discussed.

A "test of competency" was devised and administered following the classroom work in order to measure the pupils' levels of competence in using Expert Builder, to identify the difficulties which they experienced and to try to clarify pupils' mental models of the software. The test is described in Chapter 7 and the results are presented and discussed in this chapter.

The chapter concludes with a discussion of the main issues which emerged about children building computer based models from both the classroom work and the test. These issues were the range of models that were constructed, manipulation of the interface, developing a mental model of the modelling metaphor, starting modelling, the nature of modelling tasks, teacher intervention and the relationship between learning and modelling.

8.1 Description and discussion of the modelling work

8.1.1 School A

In this school the class participating in the study was a small one consisting of predominantly year 6 pupils (aged 10 to 11) with some year 5 pupils (aged 9 to 10). There was one computer in the classroom and the teacher organised its use so that pupils took turns to use it for particular purposes whenever its use was appropriate for their work. During the first part of the autumn term the class was working on a topic about holidays as part of a study of the Far East. This work took place over about three weeks. During the second part of the autumn term the class topic was energy and several groups built models on conserving energy in the home over a period of five weeks. During the early part of the spring term the class was studying developments of technologies and the class used Expert Builder to develop a system based on 'Connections: a history of technology.' by James Burke.

8.1.1.1 Work on holidays and hotels

The first model, about where to go on holiday (see Figure 8.1) was built by the teacher working with the pupils in small groups after they had discussed visiting the Far East. This work was not observed but data was collected from informal interviews with the teacher and discussions with the pupils.

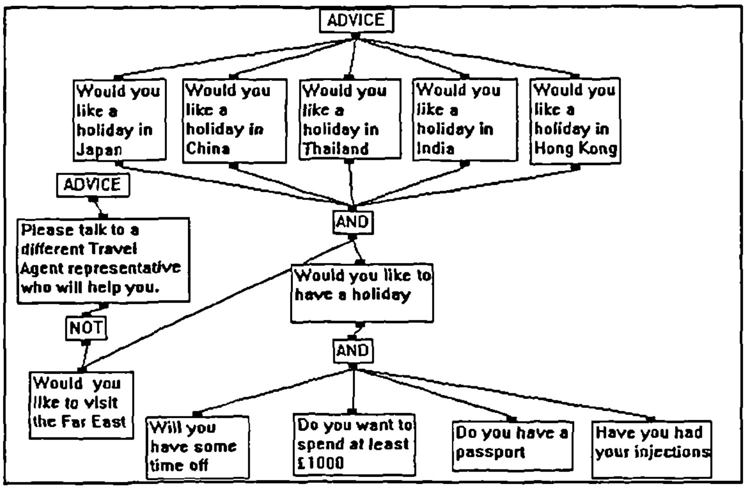

Figure 8.1 The first model, constructed by the teacher in School A, about where to go on holiday

The "holidays" model had a fairly complex structure because the teacher tried to incorporate all the factors that affect a decision about whether you want a holiday in the Far East as well as considering which countries you might choose. These were the points that he had focused on in class discussions. The teacher wanted the model to ask questions about all the factors that would need to be considered and then suggest possible Far East destinations. He had hoped to extend the model to help someone to decide which Far Eastern country to visit but he decided that adding this to the model would make it too complex. The model did run in the order that the teacher expected but the clauses were phrased as questions instead of statements so that when the system formed questions the wording was inappropriate, e.g. "Is it true that Would you like to visit the Far East?" This suggested that the teacher had not explored the environment prior to embarking on the model building exercise with the pupils. Discussion with the teacher revealed that he had spent a little time "playing" with the software and after a short time he had felt confident in trying it out with the pupils. He had not noticed that the system rephrased statements that were "leaves" in the diagram as questions. This may have been because the text "Is it true that" in the question dialogue box did not stand out and the users attention was focused on the text that they had input because this was what they were particularly interested in rather than the standard system output.

The main problem that this teacher appeared to be having was that he wanted to create a fairly complex model and this may have been difficult for the pupils to understand and so may not have helped the pupils to structure the models themselves. In subsequent activities he opted for a simpler rule structure.

Other groups went on to construct a model to advise someone about which hotel to choose. The pupils worked in groups of 3, one group started the model and subsequent groups added to it. They used travel brochures as source material. One of these sessions was observed. There was a class discussion of about 10 minutes where the teacher reminded the class of how Expert Builder worked and what they were aiming to do. He demonstrated running the "holidays" model and then showed a model about choosing a hotel which had been partly built by a previous group (Figure 8.2). This model had a much simpler structure than the "holidays" model and was easier for pupils to build up.

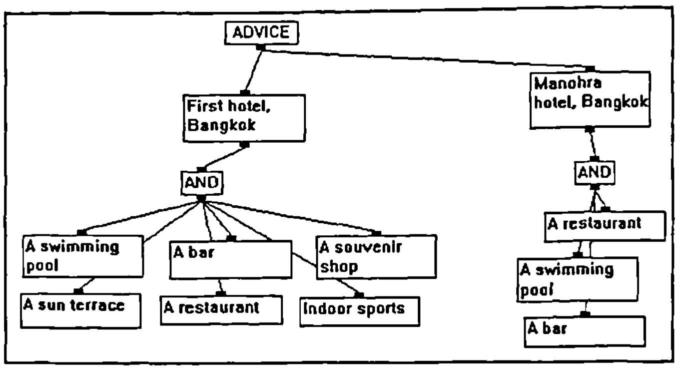

Figure 8.2 A model to choose a hotel, constructed by a group in School A

The teacher selected a group to continue working on the computer and reminded other groups about what work they needed to do. The teacher acted as tutor to the three pupils working at the computer while the rest of the class were doing other activities. He approached the model building exercise as an exploratory one in which he was learning along with the pupils as he discovered more features of the system. This was the first time these pupils had actually used Expert Builder and the teacher led them through step by step building up the model. The pupils had not used mouse-controlled software before and much of the effort was devoted to using the mouse and becoming familiar with the tools. By the end of the hour's session all three pupils had some hands-on experience and were becoming fairly competent in using the tools. The teacher led the pupils into deciding the logical structure by questioning them about the facilities available in the hotels, which they ascertained by reading the brochure.

When testing the model it became apparent that a hotel would be recommended even if it did not have all the facilities that the user wanted so the teacher introduced the use of NOT. He did this by asking the pupils to suggest a way that they might build the model so that it was possible to select a hotel that has certain facilities and does NOT have others. Pupils suggested using a NOT. The teacher initially led the pupils to link the NOT to three conditions resulting in the error message "*NOT may only have one downward link*". One of the pupils, Vivian, suggested having a NOT box for each condition, which would have been an effective way of building the model but the teacher suggested connecting all the clauses to an AND and then using the NOT. Having guided them to produce this structure, he left them to add and connect boxes for a few minutes at a time while he helped other groups. At the end of this session the model was as shown in Figure 8.3.

The pupils had connected the boxes to reflect the facilities available in each hotel. The user was recommended a hotel based on what facilities he did and did not want. The resulting model was not as the group intended since they were trying to make the system recommend the hotel only if it had all the facilities that the user selected so they needed to use NOT OR (NOR) and they had actually used NOT AND (NAND).

Neither the teacher nor the pupils realised this problem at the time although the teacher was aware that he was not always getting the result he expected.

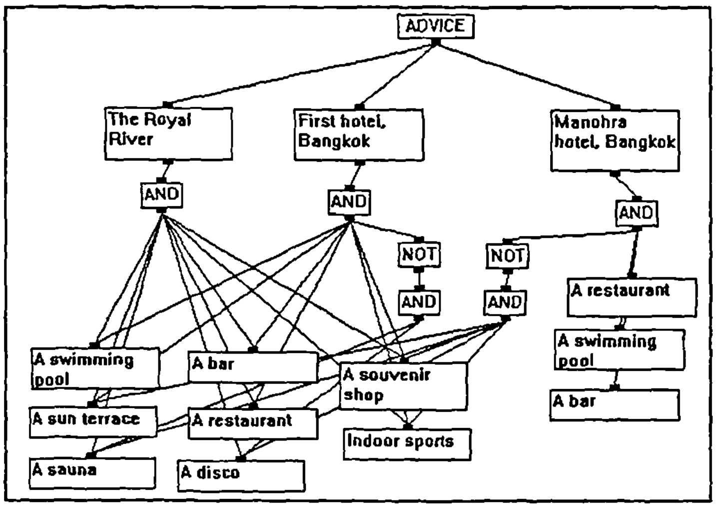

Figure 8.3 The "hotels" model after it had been worked on by a group of children in School A.

A discussion with the teacher after the lesson revealed that his knowledge of the logical combinations of AND, NOT and OR was rather confused. The complex use of NOT in this model made the task more difficult to understand. A discussion of these complex logical connectives would have been too difficult for most of these pupils. It would have been possible to introduce a simpler use of NOT to the pupils, e.g. as shown in Figure 8.4 if the teacher had a greater understanding of logical combinations or if the teacher had followed up Vivian's suggestion of having a NOT box for each condition.

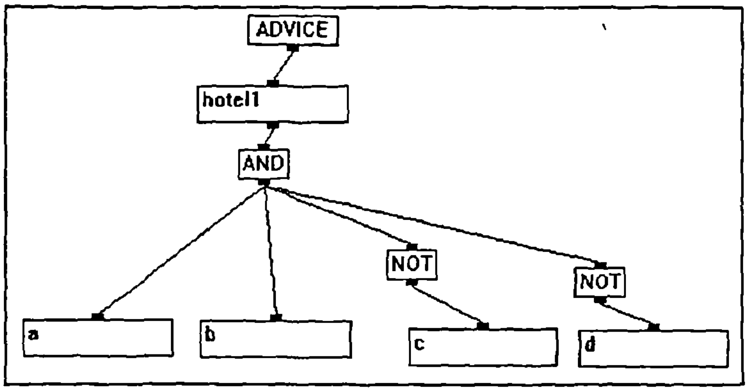

Figure 8.4 A simpler use of NOT

Two more groups worked on this model. They started by testing the model and then went on to modify it. The final version of this model is shown in Figure 8.5. The teacher decided not to take this task any further as more work on this system would be repetitive. He showed them how to change the structure to use NOT OR and the pupils tested this to show that it worked in the way that they wanted it to. He explained to the pupils that the system could be developed further to include the full range of hotels. He commented that if a large number of hotels were to be included it might be better to use a database package to store the data.

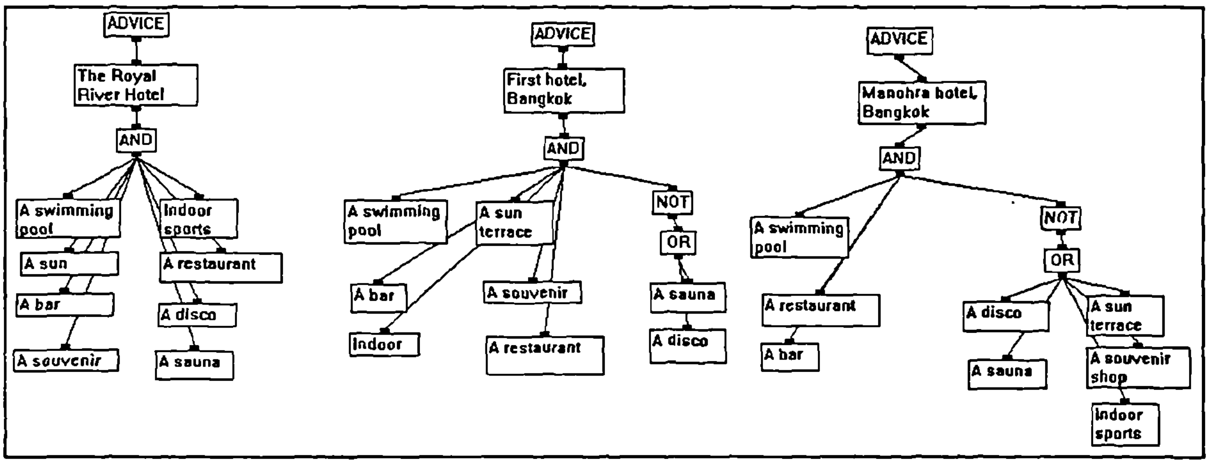

Figure 8.5 The final version of this model after it had been worked on by two more groups

Following the work on hotels, the class returned to the "holidays" model and attempted to improve the logic. In particular, the teacher wanted the model to give appropriate advice if the user said he did not have a visa or he had not had injections. The resulting model is shown in Figure 8.6. In this model they had been trying to achieve a sequence of advice by building the model up the screen. The model was a much more complex structure than the pupils would be able to attempt to build on their own and two of the clauses, *you have a visa* and *you would like to have a holiday*, have been inappropriately connected. The teacher commented that he was still learning about the features of Expert Builder himself and didn't feel confident yet about guiding the pupils through a model building exercise by asking them appropriate questions. The talk during this work was predominantly about how to use Expert Builder, e.g. the extract below occurred when the first group of three pupils were building the "hotels" model.

Teacher	*So you've got to put a box for the Royal River Hotel.*
Luke	*Yeh. I'll get a box.*
Ben	*I don't know why we don't do it underneath.*

Luke	*I can't see it now.*
Vivian	*Over there. Just there* (pointing).
Luke	*To what? Right. I'll put it in the corner here.*
Ben	*No.*
Vivian	*Yeh that'll do.*
Ben	*OK.*
Vivian	*No the arrow's got to be up there.* (Luke typing while cursor in wrong box.)
Luke	*It is.*
Vivian	*No its not. Well its down here. Its flashing. Its flashing. Look I'll show you.* (Vivian clicks in right box).
Luke	*The Where's R? R Y* (typing).
Ben	*Capital. Its a capital.*
Vivian	*The R O Y.*
Luke	*Then it'll be L E.*
Ben	*No A L.*
Luke	*Oh.*

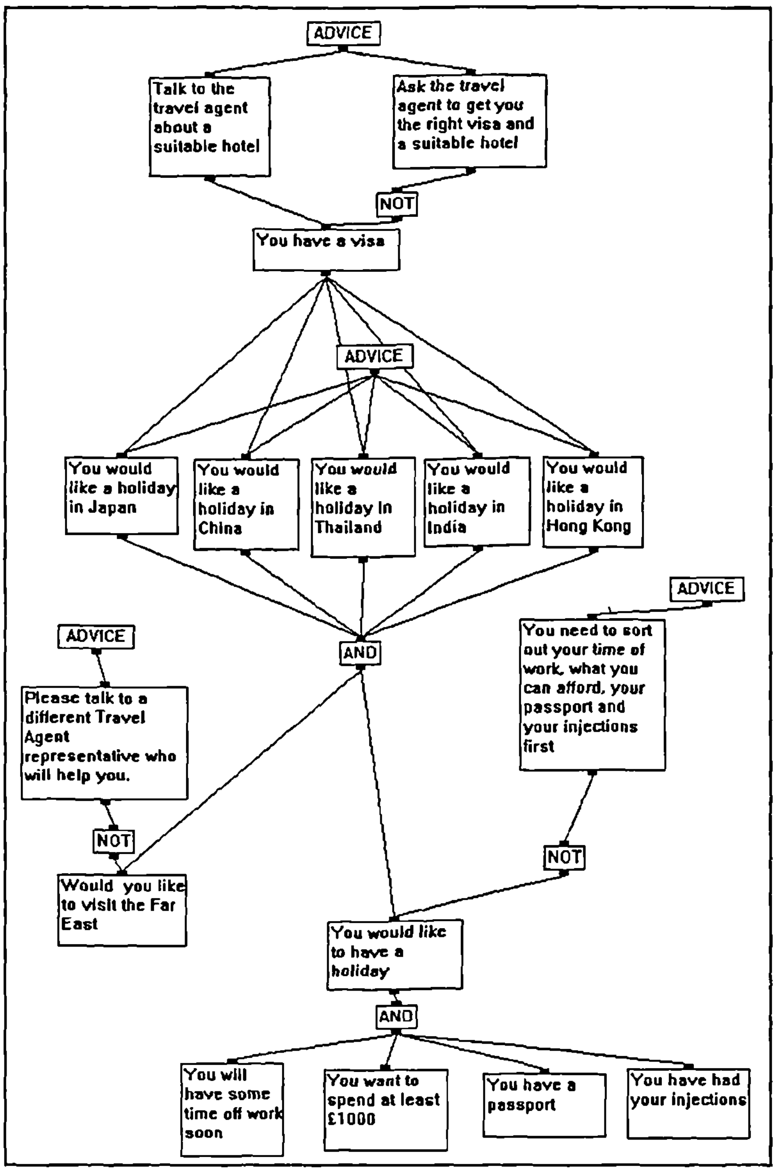

Figure 8.6 The extended holiday model

8.1.1.2 Work on conserving energy

During the next topic on energy and how to conserve it, four groups of two or three pupils constructed systems which would advise people on how to save energy. They had been investigating and discussing various aspects of energy and using source material, including a number of posters from British Gas, the Electricity Council and the United Kingdom Atomic Energy Authority. The teacher set the task which was to build a model that would advise people how to save energy. He guided the pupils to make an advice statement and then to think about the conditions under which this would apply. He then helped the pupils when they needed it but by this stage the pupils were able to work on their own more and some of them had discovered features of the system which the teacher was not aware of. They were quite prepared to experiment and they tested their models at frequent intervals to see whether they worked in the way that they had intended and they frequently made changes as a result of testing. They looked at each others models and tested them but were not very critical. They often borrowed ideas and techniques that they noticed in each others' models to use in their own and the resulting models therefore have quite similar structures. One group discovered the structure shown in Figure 8.7. They liked the way that they could make the system admonish the user if he did not follow their advice and so they and the other groups adopted this technique for their rules. The rules in their model were arranged from left to right across the page whereas in Figure 8.7 they have been rearranged into two rows.

When they had built the structure of the model, the pupils were shown how to write explanations for the clauses. This activity was similar to cooperative writing with a word processor except that the task was pre-structured by the pupils' own model and has a clear purpose. The teacher was able to leave the group to carry on with the activity while he spent considerable time with others who were constructing electrical circuits. Nevertheless he returned at regular intervals and prompted the pupils to explain the clauses.

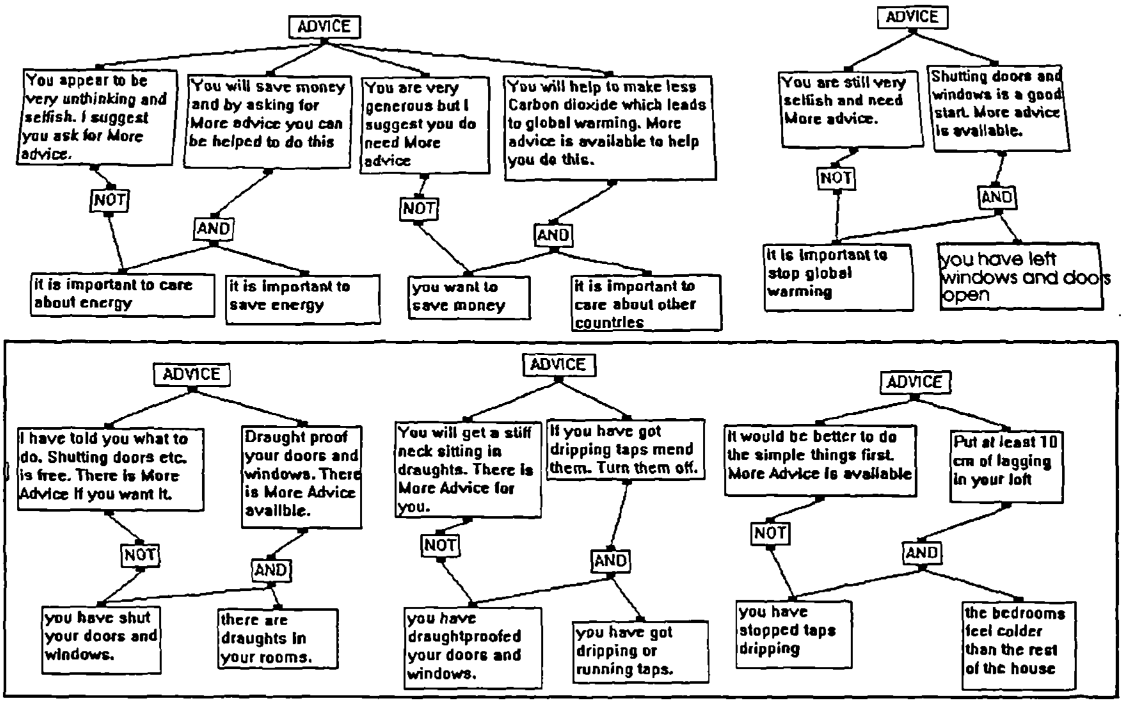

Figure 8.7 A model about conserving energy built by a group of children in School A

One of the more able groups of pupils added explanations with considerable depth following discussion with the teacher:

Clause	*Draught proof your doors and windows.*
Explanation:	*If draughts blow cold air into your house through small gaps in door or window frames, you will have to use up extra energy - coal, gas, oil or electricity being burned up in fires or central heating boilers. So keeping your home warm will be more expensive. You save money, you don't use so much energy, less fossil or nuclear fuel is used and we will produce less Carbon dioxide. This is the gas which causes global warming and could mean the ice caps melting and flooding low lands.*
Clause	*If you have got dripping taps mend them. Turn them off.*
Explanation:	*A hot tap wastes more money and energy than a cold tap because hot water needs to be heated up with energy. A dripping cold tap wastes water while a hot tap wastes water and energy.*

This knowledge was obtained from posters, other materials and class discussion and these more able pupils were able to restructure it into their model with some help from the teacher. The less able pupils had some difficulty in understanding the need for explaining the statements rather than simply restating them. In this extract from one of the transcripts, Ben took the attitude that the explanations were obvious - "*because it saves energy*" but Rena asked "*why*" and "*What else can we put*". However, they did not add any depth to their explanations until prompted by the teacher (see below).

Ben	*If any of your appliances is on* (reading) *turn T U R N.*

Rena	*If any of your appliances is on* (Ben typing - holds down a key by mistake).
Ben	*Delete, delete, delete, delete T U R N* (spelling).
Rena	*Them T H E M* (spelling) *off space.*
Ben	*O F F* (spelling).
Rena	*Why - do you turn them off?*
Ben	*Because it saves energy.*
Rena	*Yeh, because* (pause). *If any of your appliances are on, turn them off* (reading). *What else can we put? Philip, bring it up.*
Ben	*Philip stop messing about. It doesn't matter Rena if you move that, see.*
Rena	*Yeh, I know. We could do - er. OK. Cancel. Help. Save.* (reading screen buttons).
Ben	*That says get does not say cancel. What are you talking about then? OK. Help. Save. We want to save it don't we.*
Rena	*No, let's just see if we can write some more - um.*
Ben	*Put it saves money and energy.*
Rena	*Because it saves money and energy.*
Rena	*Could we write anything else.*
Ben	*No, we can't. Save.* (Rena presses save) *That's it. Good but more advice is available by clicking* (reading clauses). *We write that* (muttering) (pause).
Ben	*Yeh, OK. Go on Philip - further down, that's it.* (Philip selecting clause with mouse) *Go on write then.*
Rena	*What shall I write?*
Ben	*Um - if* (pause).
Philip	*If your doors and windows are open, shut them.*
Rena	*Oh yeh. Where's f* (typing) *I've lost f. Oh, yeh. What is it?*
Ben	*If any of your doors and windows are open, please shut 'em.* (Rena typing) *Pause.*
Rena	*If any of your doors*
Ben	*Or windows*
Rena	*Or windows are open*
Ben	*Please shut them.*
Rena	*If any of your doors or windows are open please shut them.*
Teacher	*Pardon me for saying so but shut all your windows and doors. If any of your doors and windows are open shut them. All you've done is repeat the advice, you haven't said why. I'm asking you the question 'Why?' and all it says is "If they're open, shut them."*
Ben	*Cos it saves*
Teacher	*You haven't explained anything. What happens to a warm room on a cold day if you leave the doors and windows open?*
Ben	*You will get cold.*
Teacher	*Yeh. The warmth goes out of the window doesn't it, which is a waste isn't it? So this is an explanation of why you've said that. Don't just repeat it. I mean, if I ask you what the meaning of the word empty is - if I ask you what does empty that jug mean, its no good telling me that empty that jug means that you empty the jug is it? Because you've just used the same words so you haven't explained anything - you've got to say 'why'.*
Rena	*Right. If you shut all your doors and windows.*
Ben	*You won't get cold.*
Rena	*No, you can save energy.*

Ben *Go on then, write."*

The clauses and explanations for the model constructed by Rena, Ben and Philip are shown in Figure 8.8 and the model diagram is shown in Figure 8.9.

ADVICE

any of your appliances have been left on when not in use.
[If any of your appliances are on turn them off.]

Good but more advice is available for saving energy by clicking the mouse on More advice

I gave you some advice. Why didn't you use it ? There is More Advice if you click on that box.

I told you what to do, so please take notice. You clearly need More Advice.

Shut all your windows and doors. There is more advice for you.
[If you shut all your doors and windows you are saving energy. If you leave some of your doors and windows open all the warm air will go out and the cold air will come in.]

some of your doors are open

some of your windows are open

Switch off all your appliances. There is More Advice for you.
[Switching off all your appliances saves money and energy. Click on the More Advice box with the left hand button of the mouse.]

Turn of all your taps. There is More Advice for you.
[If some of your taps are on you are wasting water, energy and money.]

you have left any taps on

you have shut all your windows and doors

you have turned off all your taps ?

Figure 8.8 Clauses and explanations for the model constructed by Rena, Ben and Philip

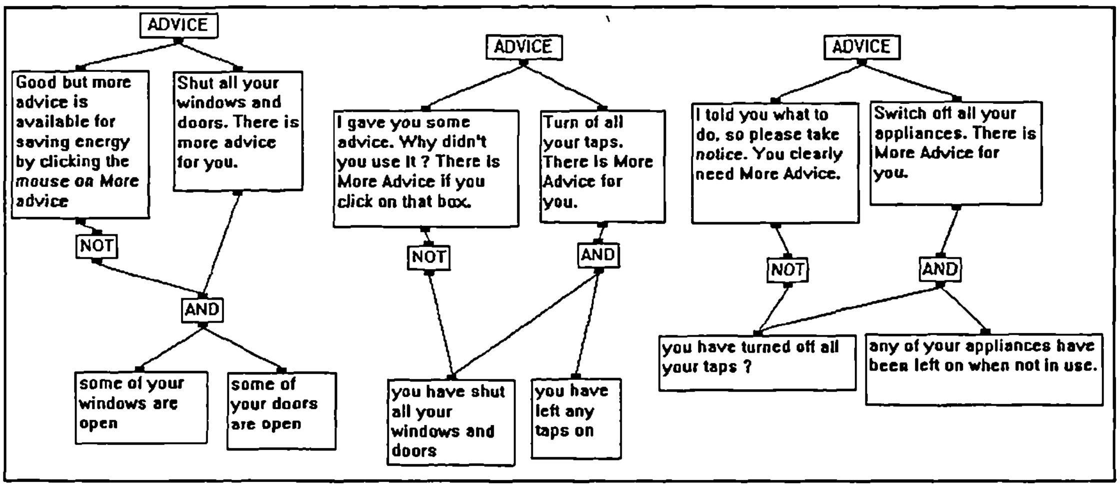

Figure 8.9 The "energy" model constructed by Rena, Ben and Philip

8.1.1.3 Work on developments of technologies

The activity based on "Connections" involved researching information from the book and then incorporating it into a system (shown in Figure 8.10) in which the user was asked whether a statement was true or false and, depending on their answer, was then given some further explanation. The statements chosen are ones where the answers are not obvious. The explanations are quite lengthy and have been created by extracting relevant information from the book. The system was built by different groups of pupils working on different questions.

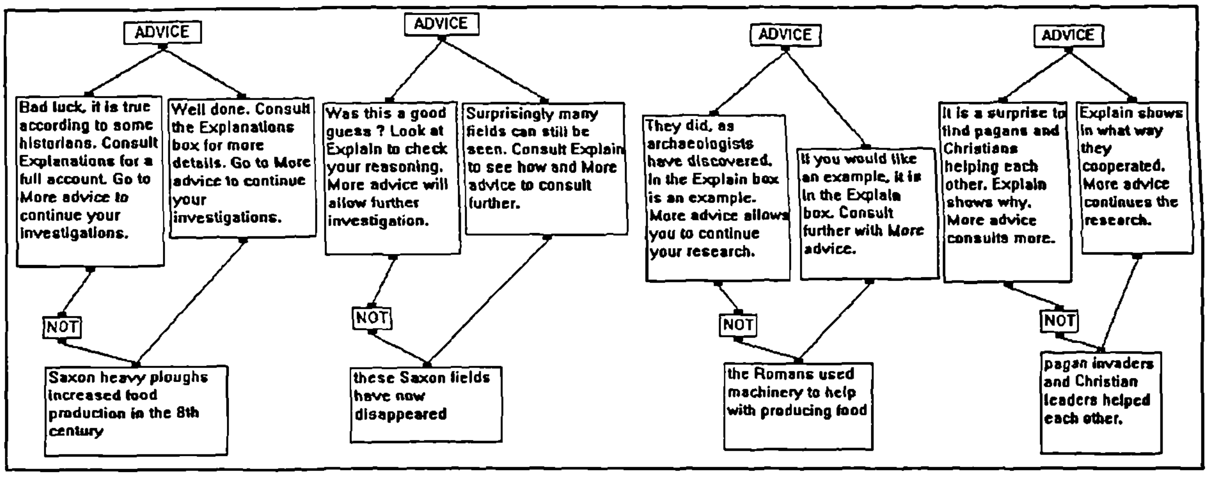

Figure 8.10 The "Connections" model built by the class in School A

This activity was again using the software to create a sequential question and response system. This was not what the software was really designed for, as is discussed later in Section 8.2.2.4, but the teacher found that this was an interesting and motivating way of encouraging pupils to research and organise their ideas.

8.1.1.4 Teaching strategy

The pupils were given considerable help throughout these modelling activities. At the beginning the work was conducted in a tutorial situation with the teacher constantly present and making suggestions and asking questions. This was possible because this was a small class and other groups of children were doing tasks which they were able to carry on with little help. In the early stages the model building process was very directed and much help was given over manipulating the software and in particular using the tools. As the pupils became more used to using the system the teacher input was directed more towards guiding the pupils into structuring the model and testing it. During the first activity on holidays the teacher attempted a fairly complex structure but then realised that the logic was becoming confusing. In subsequent activities the teacher chose simpler logical structures and at the start of the activity he had a fairly clear idea of the way he expected the model to be structured. He gave the pupils direction fairly frequently so that they did not create unworkable structures. However, on at least one occasion, a pupil created a successful structure that differed from his suggestions so there was room for experimentation despite fairly close direction. When the pupils were writing explanations the teacher spent much less time with them, simply making comments from time to time as he came past. This was possible because the results of their work were clearly seen on the screen.

8.1.1 5 Summary of work in School A

The modelling work in School A took place over the whole school year and was closely linked to other classroom work on the three topics of holidays, energy and the development of technology. Two models were completed on the first topic, both as class exercises. During this activity both the teacher and the pupils were becoming familiar with the software. Following some problems with structuring the first model the teacher chose less complex structures for subsequent modelling activities. On the second activity based on saving energy four separate groups of pupils produced models independently. All groups were successful in developing models which could be run and they incorporated explanations into their models. On the final topic about the development of technology, the class again worked collaboratively to produce one model. The nature of the models, the mistakes made and the interaction while building the models are analysed later in this chapter in Section 8.2.

8.1.2 School B

In this School the class consisted of about 30 year 5 pupils (aged 9 to 10) and year 6 pupils (aged 10 to 11). There was one computer available to the class, situated in a work area outside the main classroom and pupils, working in groups of 2 or 3, took turns to use it for particular purposes whenever its use was appropriate for their work. During the second part of the autumn term the class was working on a topic about communications and three groups of pupils built models about selecting a method of communication. In the summer term, when the class were working on a topic about the skeleton and bones, three groups built models about identifying bones.

8.1.2.1 Modelling work on the communications topic

The first modelling exercise was done during a topic on communications. Two groups of pupils built models which advised about which method of communication to use. The pupils had done some research into different methods of communication and had carried out experiments that involved timing a message being sent across the building in various ways. The teacher introduced Expert Builder to the first group (Group 1) by showing them one of the example models and then constructing a few boxes. They had discussed methods of communication and then talked about the *conditions* in which they might be appropriate. The pupils had then spent some time continuing with the model alone. The school was visited for this group's second session. At the beginning of this session the model was as shown in Figure 8.11.

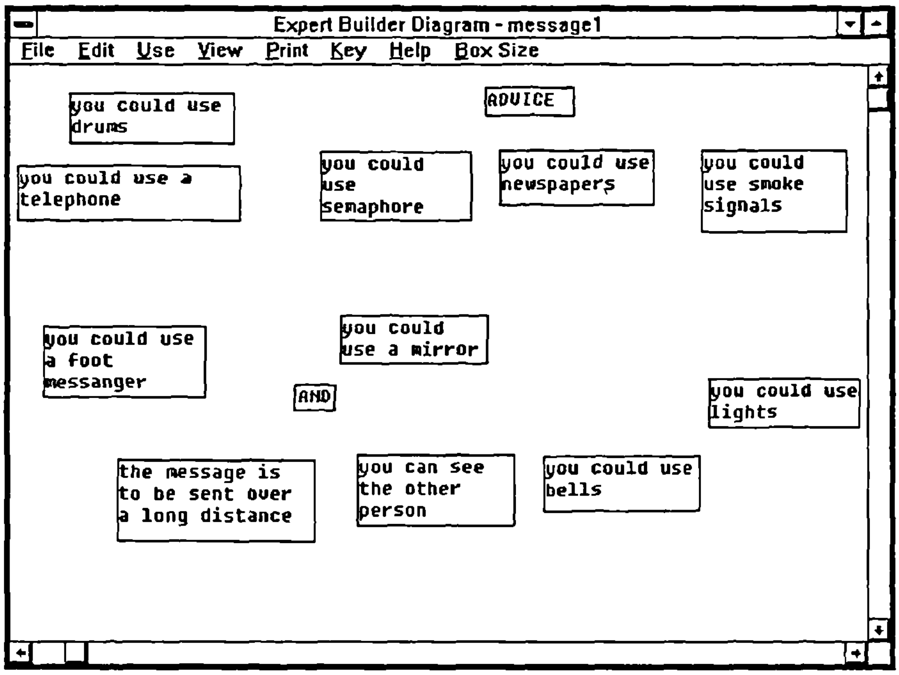

Figure 8.11 The first stage of the methods of communication model built by Group 1 in School B

The pupils were able to make, size and delete boxes. Their efforts were directed towards thinking of all the possible methods of communication and creating a box for each. The teacher came past and noticed that they now had a large number of boxes and prompted them to start thinking about when the different methods would be used, i.e. putting in conditions for the rules. He discussed with the pupils how they might reorganise the boxes. The teacher, himself, was unsure of the best arrangement because there were now too many boxes to fit on the screen. A pupil reminded him that he had suggested putting the methods of communication in a straight line across the screen. Having been shown how to use the hand the pupils were able to go on and rearrange the boxes but they started placing all the boxes in the line, including those that were conditions. On being prompted by the teacher they realised their mistake. They were shown how to use the long view to scroll the diagram and they became quite adept at coping with this relatively large diagram. They were given help when they needed it and help to overcome a bug. At the end of this session the model was as shown in Figure 8.12. They had started to make links but had not yet been able to test the model.

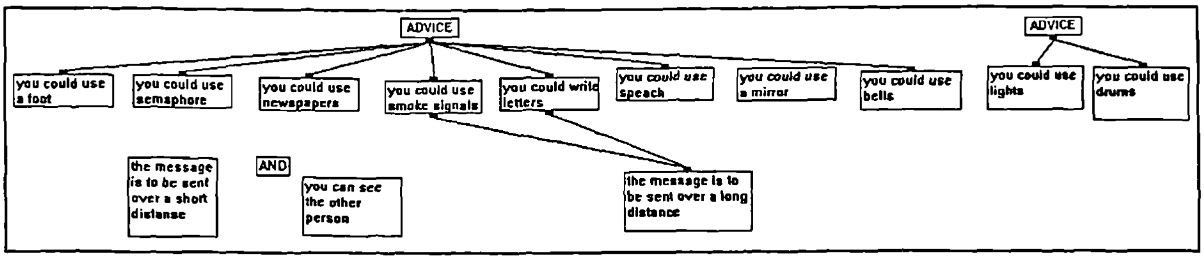

Figure 8.12 Group 1's model after the second session

During the first part of the session much of the talk was concerned with identifying all the methods of sending messages as well as a certain amount of talk about how to use the tools. When they began to reorganise the diagram the talk was focused almost entirely on how to layout the diagram and how to use the tools. This reorganising took about 45 minutes and during this time the pupils became quite adept at using the tools especially the bobbin and hand. When they were linking the boxes there was some discussion about when the different methods would be used, e.g.

Ann	*Now move that thing along there to get that little box.*
Christine	*Which little box?*
Emily	*That's it stop. Right long distance it would be to write letters wouldn't it?*
Ann	*You want it on string.*
Christine	*We need to move that one.*
Emily	*We don't need to.*
Ann	*If we move that box will it snap?* (to Experimenter).
Investigator	*No.*
Ann	*Hopefully!*
Emily	*Smoke signals - would that be a long distance?*
Christine/Ann	*Yeh.*
Ann	*Put it to the top and look at where the other one's joined. Maybe you could use the other one that's a short.*
Christine	*Ohh! Can I just get this one here*
Ann	*That's it Christine.*
Emily	*Semaphore over short. That one isn't long is it?*
Christine	*Semaphore would be a long distance.*
Emily	*Wouldn't cos you have to see it.*
Christine	*What's a foot messenger?*
Emily	*Short.*
Christine	*Oh, Oh yes. Where shall I join this to?*

Group 1 spent another session, which was not observed, on this model and at the beginning of the next session the model was as shown in Figure 8.13. They had now thought of a number of conditions and had made some progress on laying out the diagram in an appropriate way but Figure 8.13 shows that they clearly didn't understand the use of logical operators.

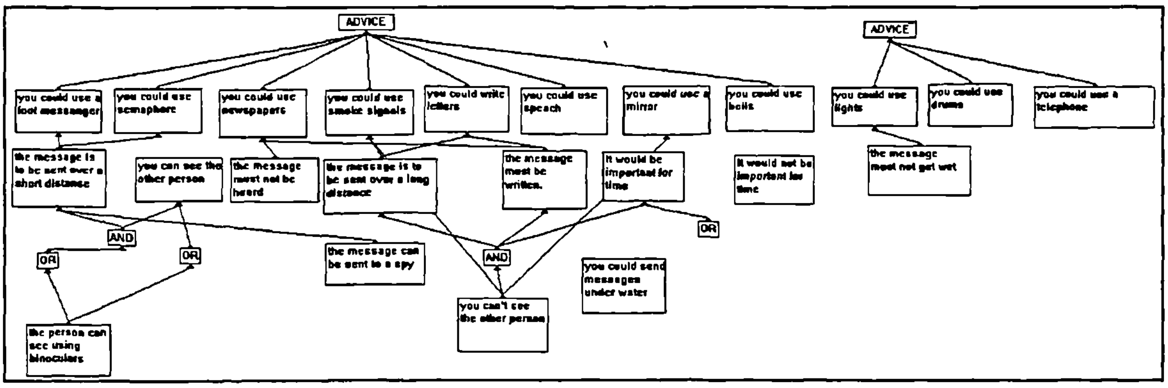

Figure 8.13 Group 1's model after the third session

During this next session, the group needed some help in examining the model and making use of the logical operators so that they could test it. They were thinking about the conditions under which each method applied but having created such a complex model they would probably not have been able to "debug" it unaided. The final model is shown in Figure 8.14. Although the text may be too small to read, the figure shows that they have restructured the model so that the logical operators are linked correctly.

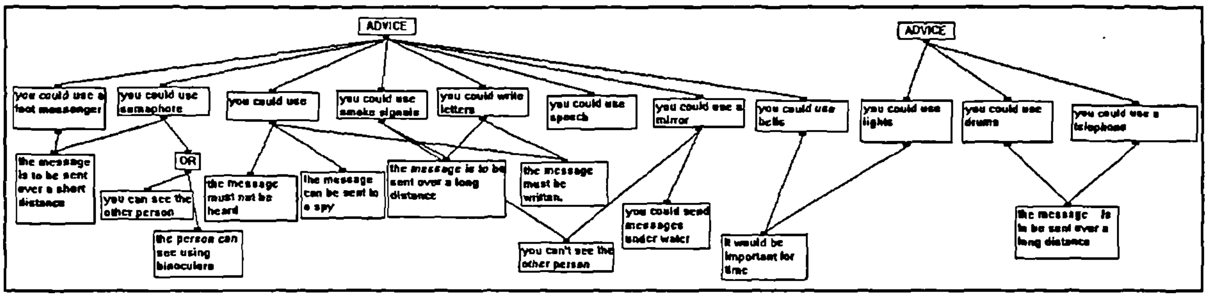

Figure 8.14 Group 1's final model about communication methods

Another group of two boys (Group 2) constructed a similar model on methods of communication. The teacher had introduced them to Expert Builder by showing them the example model about choosing a method of transport to get to school and showing them the model built by Group 1. By the end of this first session their model was as shown in Figure 8.15

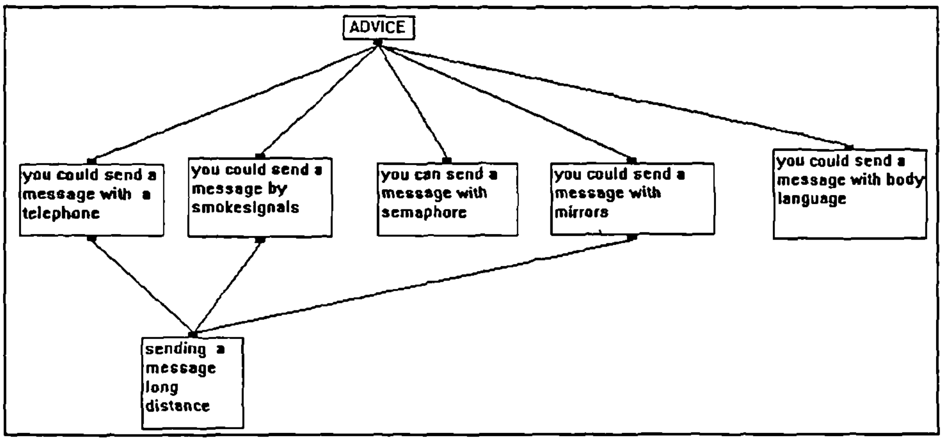

Figure 8.15 Group 2's model at the end of the first session

During the second session, which was observed, the boys were fairly adept at using the tools and had a fairly clear idea of how to structure their model as can be judged from the extract of their talk shown below. This was recorded while they were building the section of the model shown in Figure 8.16. They had not tested their model so they were shown how to do that by me and helped to find an empty box that prevented the model from running.

James	*What could we do?*
Anthony	*We could do sending a message by er* (pause). *You could use foot. That one's short and longer.*
James	*So you could use foot.*
Anthony	*You don't need to put you could use anyway. You ask questions and there's about 4 possible answers.* (James typing).
James	*What shall I put? Sending a message on foot?*
Anthony	*No sending a message - I don't know a bit longer distance. Lets put by foot.*
James	*That's the same as that really.*
Anthony	*Anyway that'll do.*
James	*Lets go and get that.*
Anthony	*Go on then - you could send a message.* (James typing).
James	*Oh where did the bottom go?* (bottom of box not drawn = a bug).
Anthony	*The bottoms going walkabouts.* (James links boxes).
James	*You could do a foot message by long distance as well really. It'd take a few days though. Right, what else?*
Anthony	*Sending a message by letter sort of er sending a message* (James typing).

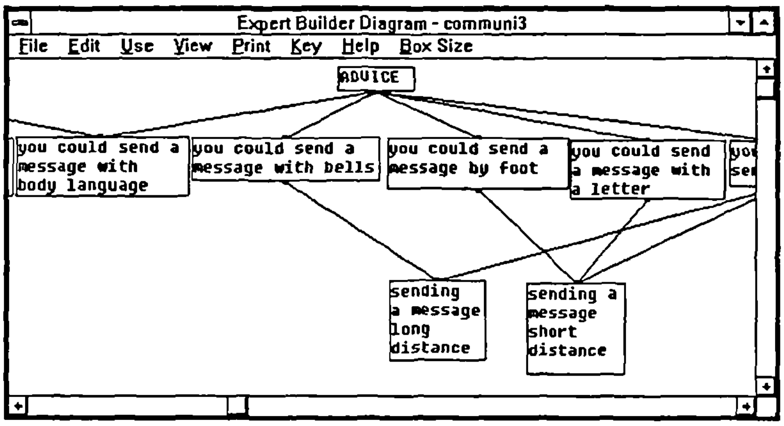

Figure 8.16 The section of model being built while the talk presented above was recorded

This pair were able to build their model with less help because they built it in sections rather than trying to put in a large number of conclusions at the start. This was probably because the teacher had given more instruction at the start of the activity.

8.1.2.2 Modelling work on the "bones" topic

The other topic where Expert Builder was used was about the skeleton and bones. The class had looked at a plastic skeleton and some animal bones, which the teacher had brought in. They had discussed why the body needed a skeleton and some of the functions of the various parts. Three groups attempted to build models during this topic and one of these groups was observed during two of their sessions on the computer. These 2 boys were building a model which would identify a bone. They were referring to 2 books, the model skeleton and some bones. The teacher had introduced the software by showing them one of the example models and had then worked with them to build the first part of the model shown in Figure 8.17.

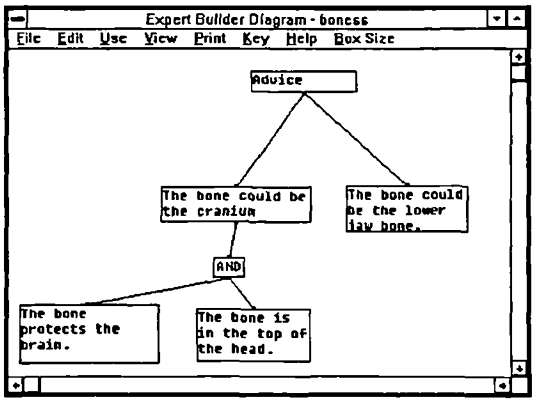

Figure 8.17 The first part of the model built by Group 2 with help from the teacher

The teacher had then allowed them to continue alone and they had rapidly added more boxes to create quite a complex structure (Figure 8.18).

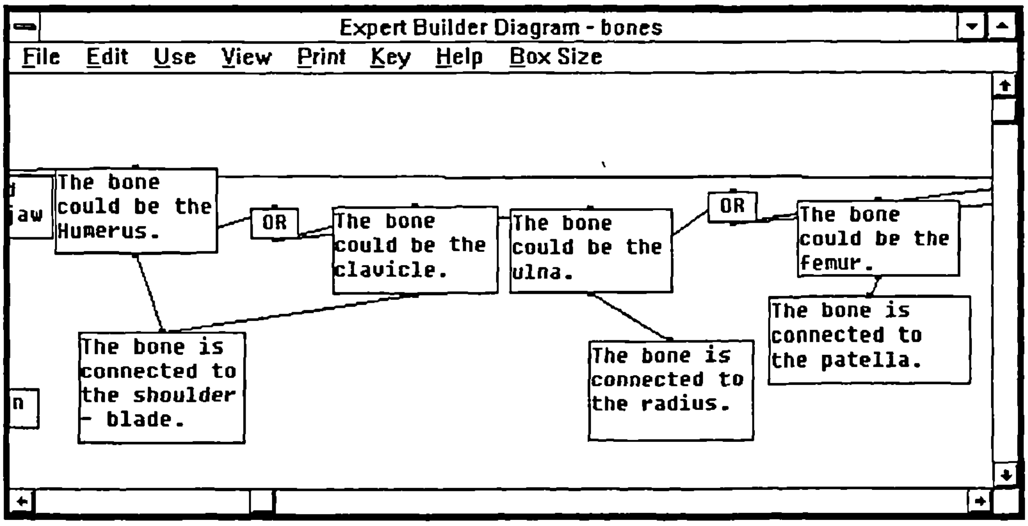

Figure 8.18 Part of Group 2's model after the first session, showing the incorrect structure

There were two problems with their model:

- They had deleted the original advice box and replaced it with a box in which they had typed Advice. This meant that when they tested the model the boxes changed colour to show their status but no advice was presented to the user. (This problem was partially overcome in a more recent version of the software by not allowing the word Advice to be typed into a box.)
- They had connected the alternative conclusions together with ORs as can be seen in the part of the model below. The model could still be run but the logic was incorrect. In creating this structure they had taken note of error messages which would have insisted on the logical operators having more than one downward link and had adjusted the structure until it was possible to run the model. This showed considerable ingenuity and ability in coping with the user interface. The structure that they had created was very complex and it would have been very difficult for them to detect that it was logically incorrect.

They were given help correcting the structure of their model, which was simply to delete the OR's and connect the conclusions to advice boxes. They did this very quickly and were then shown how to test it and encouraged to test it regularly. They went on in this session, to include more bones and to make the model "cleverer", i.e. to use AND's so that each bone could be uniquely identified. This was in response to a discussion with the teacher. During the following discussion they are improving the rules by making the conditions more complex:

Dean	*Er is this where we got to before. I know you start with the mouse over there. Is this where we've just got to? I think it is. Yes this is it. We need that across there and this here. Yes move that down* (box) *Yes now we need another box there because remember we've got to make it a bit more um*
Keith	*Clever.*
Dean	*Clever yes right.*
Keith	*Tibia.*
Dean	*What else is the tibia connected to? The tibias connected to the fibula. Where's the tibia?*
Keith	*Here it is - the shin bone.*
Dean	*Connected to the fibula which is the shin bone so its there* (model). *yes the shin bone. Look the tibia to the fibula. Now what else is the shin bone connected to?*

	Here (referring to diagram) *so this is the shin bone - 44* (the bones are numbered on the diagram and there is a key).
Keith	*45 the fibula.*
Dean	*No its connected to the um knobbly knee cap. the patella. Right there are*
Dean	(Typing) *Connected to the -. How do you spell patella?* (checks in book).
Keith	*Yes we need an AND.*
Dean	(Creates AND) *Where's the cotton reel?*
Keith	*There.*
Dean	(Connects up).
Keith	*Shall we save it again?*
Dean	*We don't need to.*
Keith	*Box.*
Dean	*We've always got one box.*
Keith	*Why've you put a box there?*
Teacher	(Has just come to see how they are getting on) *so the system will only give us tibia if these 2 conditions are true -yes? The tarsus is just this one.*
Dean	*No hang on. We're going to put another box there and an AND there so the bone is connected to the tarsus and the bone is connected to the patella.*
Keith	*We haven't done that yet.*
Dean	*No we haven't done that bit we've been doing this bit round here.*
Teacher	*I see. So where else is the tarsus connected besides the fibula then?*
Dean	*Tarsus. wait a minute - cant remember* (looks in book) *Where is it?*
Keith	*I've forgotten where it is. Fibula.*
Dean	*No the fibula is just. There's the femur. There's the fibula.*
Keith	*Yes - shin bone.*

The activity was developing a variety of skills. They were selecting information from two books and comparing diagrams with a model skeleton. In further sessions, of approximately two hours duration, that were not observed, they added further bones so that the model was quite comprehensive. In a further session, that was observed, they went on to add explanations to their model. The final model contained brief explanations for nearly all the conclusions e.g.:

Clause	*The bone could be the clavicle.*
Explanation	*The clavicle moves when you move your shoulder.*
Clause	*The bone could be the breast bone*
Explanation	*The bone protects the heart and lungs. The bone is near the neck. The bone is in the top half of the body.*
Clause	*The bone could be the femur*
Explanation	*The bone is in the upper leg. The top joint on the bone is a ball and socket.*

The diagram for the final model, which was quite extensive and detailed is shown in Figure 8.19.

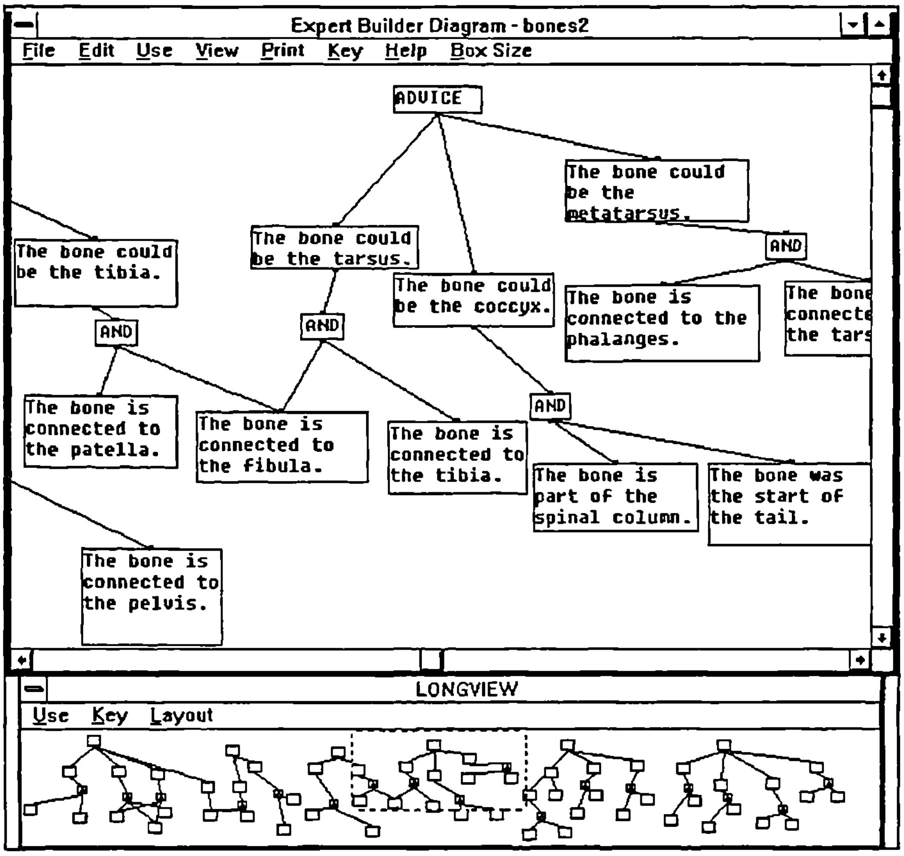

Figure 8.19 Dean and Keith's final model

The boys were very pleased with the model and the teacher was pleased with their progress particularly as Keith had been under achieving. He normally put little effort into his work and his written work was very poor. Dean and Keith's "Bones" activity was used to examine taxonomies of learning and is discussed further in Chapter 9.

Of the other two groups who attempted this exercise, one was not observed and the other was observed for only a very short time. The former group was reported by the teacher to have made good progress and to have found the task interesting. The other group, which was observed briefly, consisted of two girls, who the teacher regarded as intellectually well below average. The teacher expected the task to be beyond their capabilities. They were able to manipulate the tools and user interface but could only attempt to create the model with considerable help.

8.1.2.3 Teaching strategy

The approach in School B was less directed than in School A. The teacher showed the pupils how Expert Builder worked by demonstrating running an example model and showed them how to create boxes. In later "bones" activities he spent some time starting the model with the pupils to help them to structure the model. The teacher intervened less than in School A. This was partly because the class was larger and so other groups needed more attention and also because the computer was not in the classroom. A further factor was that the teacher wanted to encourage the pupils to experiment and try out their ideas. He expected pupils to work in small groups unsupervised and to use their initiative. He had a general idea of how he expected the model to be structured but he had not explored all the features of Expert Builder himself and was prepared to learn from the pupils. He was not sure of the best strategy and he was not given any guidance on this. It was significant that in later activities he spent more time, at the outset, helping pupils to construct a small section of model that worked rather than focusing only on how the tools worked. One of the effects of more freedom for the pupils and less teacher direction was that, on several occasions, pupils created inappropriate model structures and needed help in restructuring their diagrams.

8.1.2.4 Summary of work in School B

The modelling work in School B took place over the whole school year although little modelling work was done in the spring term owing to other commitments. The work was part of classroom work on two different topics. Altogether five groups of pupils worked on their own models after a relatively brief introduction to the software. Four of these groups succeeded in creating models which worked although they all had some help from both the teacher and myself. The nature of the models, the mistakes made and the interaction while building the models are analysed later in this chapter in Section 8.2. One group, in particular, became very interested in this model building task and persisted to build a quite large and complex model. A large amount of this group's work was recorded and this was used for a detailed analysis of the modelling task which is presented in Chapter 9.

8.1.3 School C

The year 6 class (aged 10-11) was working on a topic about the earth, which included rock formation, volcanoes, earthquakes and the soil. A student was taking the class during the study and she did not use the computers during this work. Twelve pairs of pupils were extracted from the class for two sessions and then six of the pairs for a further four sessions. I acted as tutor during this work. Each session was approximately one hour. The first session was intended as an introduction to the modelling environment. In the second session pupils started to build their models to identify rocks. During a further full day pupils, including those who had not previously taken part in the study, were given the opportunity, on a voluntary basis, to build models of their own choice.

8.1.3.1 The first session

During the first session the pupils were introduced to Expert Builder by being shown how to build a simple model about what clothes to wear depending on the weather conditions. This demonstration took about 20 minutes and the pupils then went on to try using Expert Builder themselves either to build a similar model to that demonstrated or, since some of them requested it, to build a model on their own choice of subject matter. Four of the groups had realised, during this brief demonstration, that they could use the software to construct their own models. They suggested the following topics without prompting:

- How to play penny soccer
- What type of football boots to choose
- What type of horse to buy
- How to diagnose faults in a motorbike

During this session pupils were given help whenever they needed it both with using the tools and with dealing with the logic and the modelling metaphor. Four of the boys became adept at manipulating the software very quickly, so that they were able to create and link boxes and make use of the logical operators without further help. They were advised to test their models as soon as they were observed to have built a rule structure that was testable, i.e. it had a conclusion and premise. They were then advised that in future they should test their models each time they had added a new rule structure or changed one of the existing structures. Most of the pupils needed a significant amount of help in structuring their models. They generally knew what advice they wanted their model to give but they needed to be prompted to think about the conditions under which the advice would be appropriate and then they needed to be shown how to connect the boxes to make the model work in the way that they wanted it to. They also needed to be reminded about which tools to use. Two groups had gained sufficient understanding of the use of the tools and the modelling metaphor, during the demonstration, to make rapid progress in structuring their models and they built very successful models with very little help (see Figure 8.20). The one based on choosing what clothes to wear was based on the model that was demonstrated so this only required the pupils to understand the way the system worked but the other one, about football boots, required the pupils to apply their understanding of the system metaphor to a different topic.

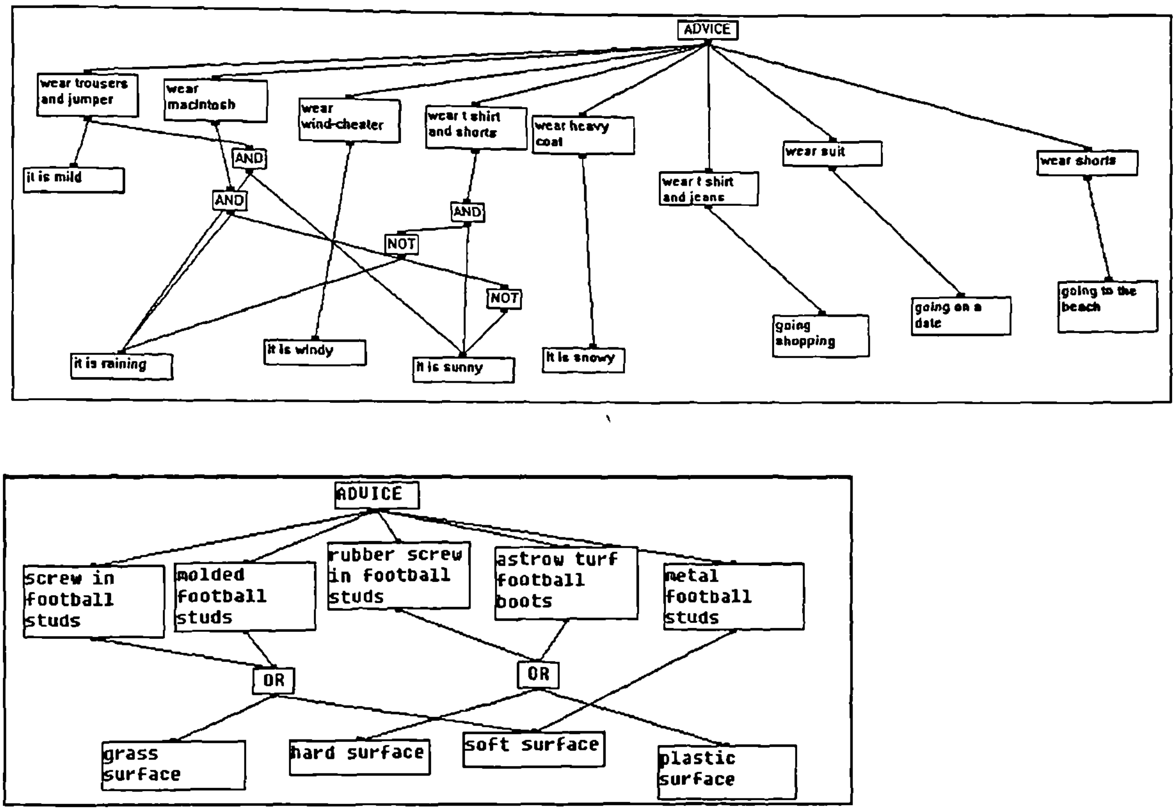

Figure 8.20 First attempts at building models by 2 groups in School C who succeeded with very little help

Most of the boys and two of the girls had quite good keyboard skills and were used to using the mouse. The teacher reported that they had done word processing throughout the school and they often used the computers in the lunch hour, mainly to play Solitaire.

8.1.3.2 The work on rocks

At the end of the first session pupils were asked to look up information about how rocks were formed in preparation for the second session. In the second session they were shown how to build a simple rule to identify one of the rocks during a discussion in which they were asked to examine the rock and suggest characteristic features. I built up the model in response to their suggestions. The rule structure was built so that the rock would first be identified by name and then the model would go on to advise the user of the rock type, i.e. sedimentary, metamorphic, etc. An example is shown in Figure 8.21.

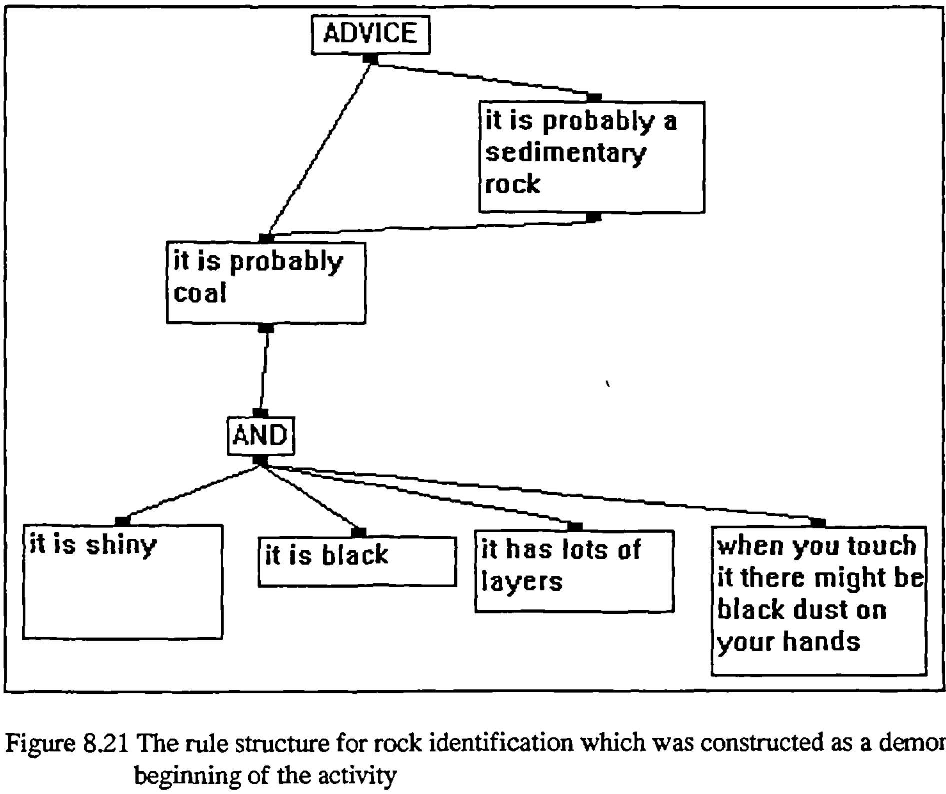

Figure 8.21 The rule structure for rock identification which was constructed as a demonstration at the beginning of the activity

The pupils then went on to build their own models to identify some of the rocks, of which they had samples. They were encouraged to use the same rule structure throughout and to write explanations for the clauses where appropriate. Five of the pairs were able to carry on and build their own models using the same rule structure but the others needed to be reminded about how to structure their rules. During the second session on the rocks models, when they had built their models to identify two or more rocks, two of the groups decided that they were not fully satisfied with the way the rule structure that they had been shown worked in their models and they asked about how they could achieve the result they required. These groups had therefore evaluated their model and detected its limitations. The problem, identified by the pupils, arose when a second sedimentary rock was included. The same clause box could be used for "*it is probably a sedimentary rock*" but because it was further to the left on the screen it would fire before the statement giving the name of the rock. The pupils wanted their model to give the name of the rock first and then state its type. This could be achieved by using unique clauses e.g. *coal is a sedimentary rock.* However it was then necessary to cut and paste the explanation text for sedimentary rock so that it was available for each conclusion about sedimentary rock. These groups had no difficulty with cutting and pasting their text. One of their models is shown in Figure 8.22 and is listed in Appendix 5.

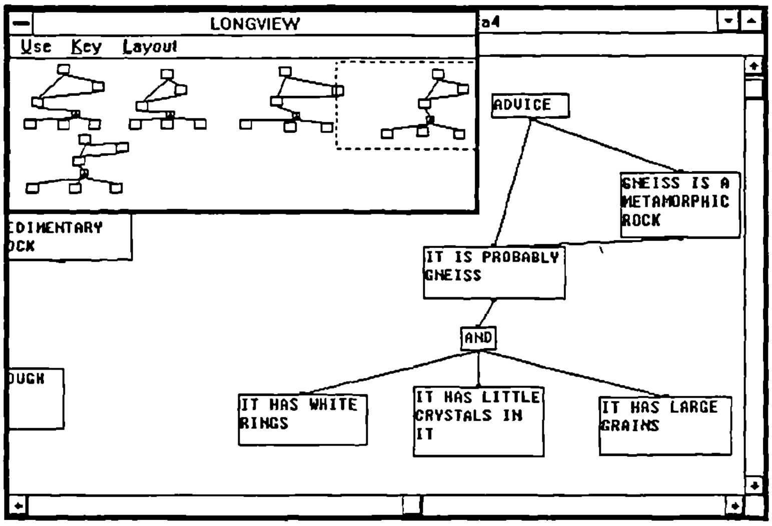

Figure 8.22 The model built by one of the groups who identified a problem in the way the model structure worked

There was a danger with this approach in that the logic of the system was inaccurate in that "Gneiss is a metamorphic rock" is always a true statement. There are obviously other ways to structure the model, e.g. the rules about rock types could all have been arranged to the right of the rules about the names of the rocks. There was a conflict here between a perceived need for the model to provide a suitable sequence of advice and to focus on creating appropriate declarative rules. In addition the task had been set so that pupils considered one rock at a time and observed its features, identified it by name and determined its type, i.e. method of formation. The problem encountered here actually reflects the real situation when geologists identify rocks. A rock can be identified by its appearance but its origin cannot always be determined simply by examining a sample. An identification model for rocks, therefore, cannot be arranged hierarchically like an animal classification system might be.

The six pairs of pupils who worked on their rocks' models over several sessions all managed to produce models that worked and identified at least two rocks. Their models also contained some explanations. The boys worked faster than the girls, mainly because they had better keyboard skills.

The activity was successful in that it encouraged the pupils to observe the rocks carefully and to think about distinguishing features. They also discussed how they could determine how the rock might have been formed and what were the uses of the rock. They were keen to make their models work and to provide useful information about the rocks.

8.1.3.3 Optional further work

Following this modelling activity the pupils were given the opportunity, on a voluntary basis, to spend half a day working at a computer in the Computer Centre using Expert Builder to construct a model of their own. Fourteen pupils opted to do this. Two of these had not taken part in the previous modelling activities although they had been shown the program by other pupils and they paired up with those who were experienced in using the software.

All the pupils came to the session with some information. The two boys (referred to as Group 1), who built the model shown in Figure 8.23, were both experienced in using Expert Builder having used it in the first six session. They must have come to the session with a fairly accurate mental model of the metaphor of Expert Builder and how they could make use of it because they constructed this model with hardly any help at all. This model took them about 3 hours to build.

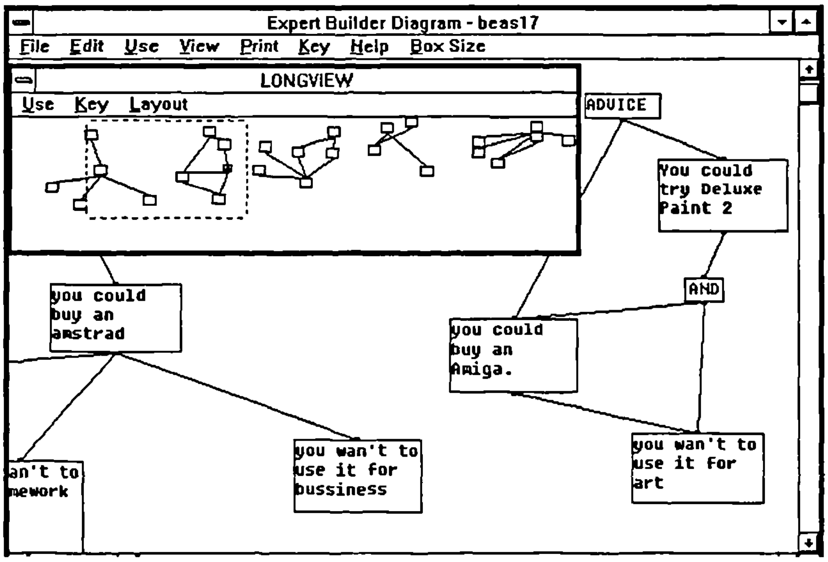

Figure 8.23 A model built by Group 1 during the optional session in School C

The rule shown on the screen dump in Figure 8.23 has a similar structure, with hierarchical advice statements, to the structure used in the "rocks" model. The rule structure shown in Figure 8.24, although they had not quite finished connecting it, was perfectly adequate for advising on a particular piece of software for a specific purpose but was different from any they had been shown previously. They discovered this structure for themselves by experimenting.

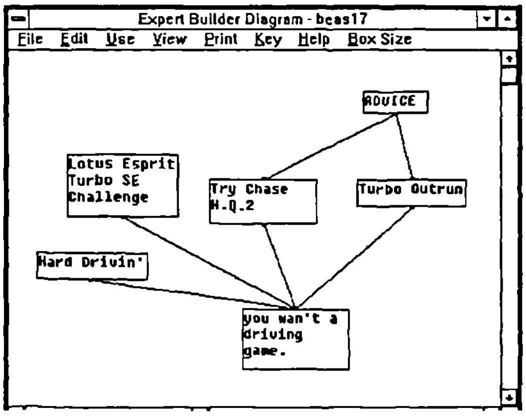

Figure 8.24 A section of the model built by Group 1 which shows a different rule structure

The model contained explanations for nearly all the advice clauses, a sample of these is shown below. The information was extracted from computer magazines.

You could buy an Amstrad

> *[You could buy an Amstrad because it is possibly the best 8-bit computer for playing games on. Amstrad make high quality business computers. If you like playing games there is a wide range of full-price and budget software.]*

You could buy an Amiga

> *[You could buy an Amiga because it is 16-bit and has 512k memory. The Amiga is brilliant for games because it's memory size enables it to create brilliant visuals and stereo sound with up to 8 instruments in one go. Also there is the Amiga 1500 and the Amiga 2000, these are high quality business computers.]*

These pupils were obviously very keen on computers and they had computers at home on which they played games. This may have enabled them to grasp the possibilities of Expert Builder and develop a mental model of its metaphor more quickly than some of the other pupils. Other groups had some ideas of the kinds of models which might be built. The topics chosen were:

- How to choose a horse
- Identifying a footballer
- Deciding where to go for a holiday
- Deciding what to wear (this group, Group 2, wanted to improve on the model which they had built in the very first session)

Group 2 had no difficulty in structuring their model but the other groups, although they had some idea of the kinds of logical structures that were possible, needed a significant amount of help in deciding how to structure their diagram. Several of the groups were able to add more rules once they were shown an appropriate rule structure.

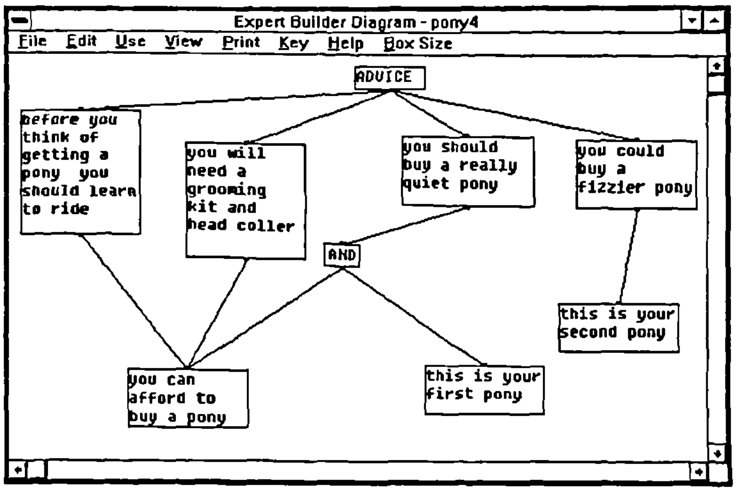

Figure 8.25 A model built by two girls (Group 3) during the optional session in School C

The model shown in Figure 8.25 was built in about two hours by two girls (Group 3) who came to the session with some knowledge which they thought could be structured into an Expert Builder model but they needed some help in structuring it. Their first attempt at constructing this model, before they were given any help, is shown in Figure 8.26.

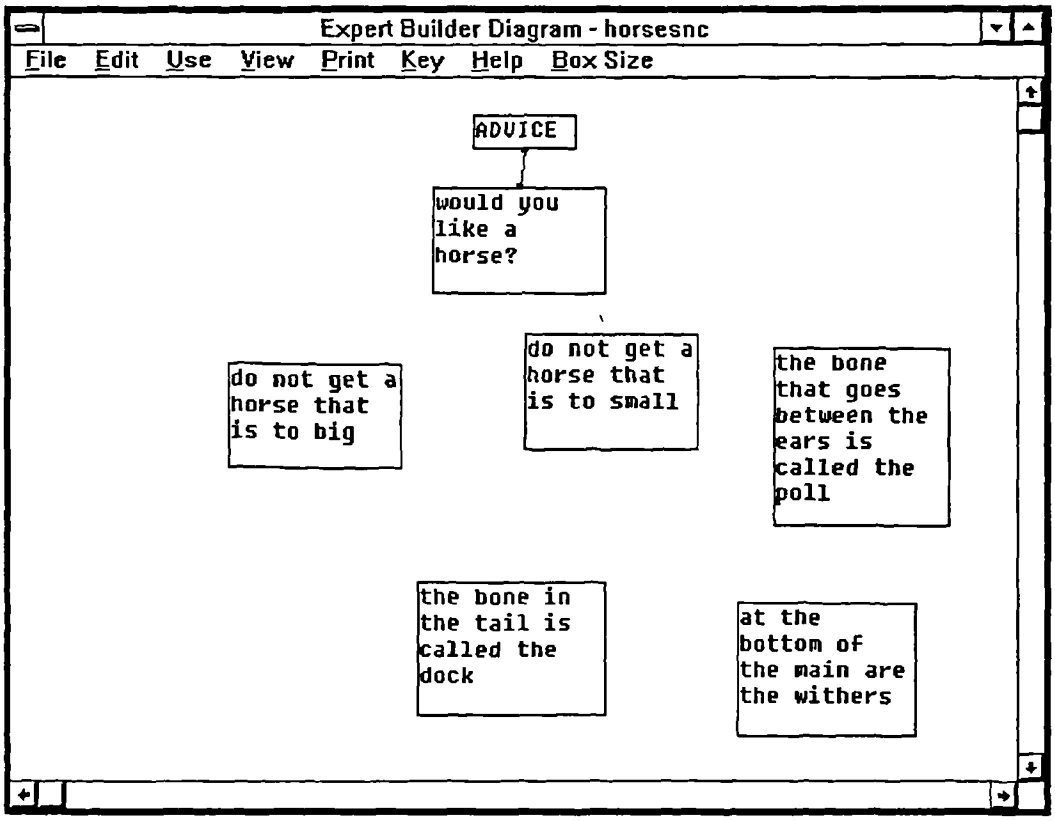

Figure 8.26 The first attempt at building the model for choosing a horse by Group 3

They appeared to have thought about the advice which they wanted to give but they had not considered any conditions. They were questioned as to whether they would advise different people to buy different types of horses and whether they would advise everyone to buy a horse.

The model in Figure 8.27 was built by another group of girls (Group 4), who may have developed a mental model of the software as merely an environment for presenting information since they wanted their model simply to present the user with information. It is also possible that they had decided to ignore other features of the system believing that they were unnecessary for their purposes. When the model was used it asked the first clause as a question and if the user answered "yes" it put up the same clause in an advice box. The girls ignored or failed to notice that the system was asking a question and asked how they could "*stop it saying the same thing twice*".

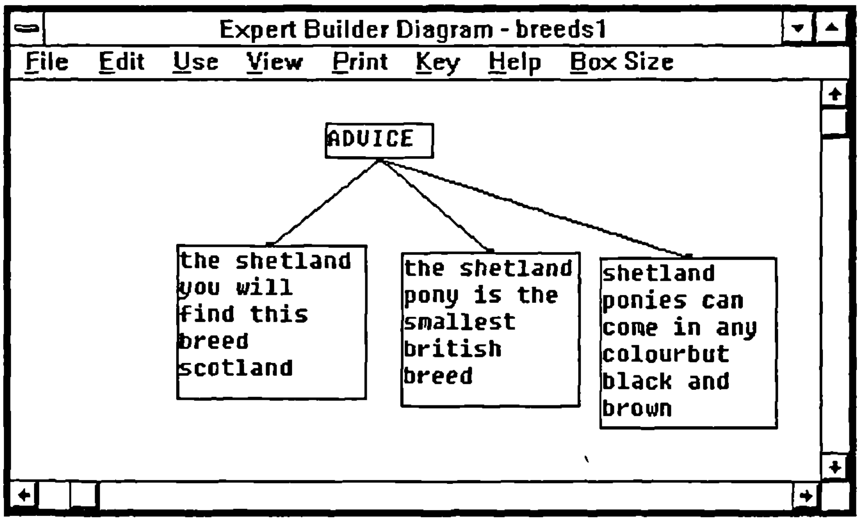

Figure 8.27 A model built by two girls (Group 4) during the optional session in School C

8.1.3.4 Teaching strategy

The approach in School C was similar to that in School B except that the teaching on the computer based modelling work was done by me and there were generally only three pairs using computers so that it was possible to respond when they needed help. The pupils were shown how Expert Builder worked by demonstrating building and running the model on selecting clothes to wear. Subsequently, pupils were given help when they asked for it or when they were observed to be having problems.

8.2 Discussion and analysis of classroom observations

In the previous section the modelling activities that took place in each school were described and specific observations were commented upon. In this section similarities and differences between the modelling activities are discussed in order to clarify the nature of the models, the range of modelling opportunities and the factors affecting modelling tasks. The interactions between pupils, between pupils and the computer and between pupils and the teacher are also discussed.

8.2.1 Selecting modelling tasks

Expert Builder was only suitable for certain types of models: those which could be expressed as heuristic rules. In Schools A and B the tasks were chosen by the teachers, both of whom had some experience of building rule based models and of using Expert Builder. The teachers had no difficulty in identifying suitable tasks that they felt could be of value to their pupils and which fitted the topics on which they were working. In School C, the task of building a model to classify and describe rocks was chosen by the investigator after the class teacher had commented that the class would be working on this topic. This was a fairly straightforward task for rule based modelling and the subject matter could be readily researched by the pupils.

There was a wide range in the capability shown by the pupils in School C when they selected their own topics for modelling. The task was difficult because the pupils were asked to think of what subject they wanted to model, collect the information they needed and decide how to structure their model. In the National Curriculum statements of attainment this kind of task was at level 9:

> "*Pupils working towards level 9 should be taught to analyse a situation, and then design, implement, assess and refine a complex model to represent it.*" (Department of Education and Science and the Welsh Office (1990)).

Level 9 would be expected to be achieved only by more able 14-16 year olds since the National Curriculum attainment scale was from 1 to 10 for children from 5-16 years of age. Therefore, at this level a much more complex model would be expected as an outcome than could reasonably be expected by 10-11 year-olds. But it was noticeable that statements below level 9 assumed that the pupils would only be expected to design the model rather than analyse the process. More than half of the groups were able to identify suitable tasks. This represented approximately 25% of the whole class since about 50% opted to participate in this activity. Several pupils were able to suggest suitable modelling tasks after only a brief 20 minute demonstration of the software. These pupils were considering knowledge with which they were very familiar and thinking about how they might use the software to produce a useful model in an area that interested them. Therefore, deciding whether Expert Builder was suitable for a particular modelling task was a skill within the grasp of more able 10 to 12 year-olds.

The study suggested that the selection of the modelling problem was very important. As discussed in Section 8.1.1, in School A the first modelling problem, chosen by the teacher, resulted in a complex model structure that may have hindered the development of the pupils' mental models of the modelling environment. Tasks were more successful where the teacher directed the pupils towards a simple effective rule structure. The "bones" model is a good example where pupils were selecting information from diagrams and text, observing the actual skeleton and thinking about organising this knowledge into a given rule structure.

In addition to considering the type of model structure that would be likely to emerge for a particular problem it was also important to consider the knowledge that would be needed. There was some evidence suggesting that familiarity with the knowledge required for the model simplified the modelling task. In School C where pupils were encouraged to design, build and test their own models starting with their own ideas, a considerable degree of success was achieved in building models that fulfilled their purposes. Some of the pupils very quickly learnt how to manipulate the diagram and make use of the metaphor. This may have been because the task became simpler overall, since the pupils did not need to extend their knowledge of the subject matter significantly. Another factor that may have contributed to this success was a higher level of motivation. Even though there was a high level of interest and motivation throughout the activities some pupils were keen to use the computer but less keen to grapple with the subject matter of the models. The pupils who were building models of their own choosing may have felt a sense of ownership which would have increased motivation. It was also possible that pupils' previous experience in using computers contributed to their success because this varied within and between schools. For example, most of the girls in School C, who had had less experience in using the computers than the boys, were slower in learning to manipulate the software.

8.2.2 The nature of the models

Within the sphere of tasks that are suited to rule-based modelling, there is a range of types of models and wide variation in the level of complexity of the modelling process. This is partly due to how the modeller tackles the task but is also influenced by the nature of the models themselves. Rule based models were classified into the following groups (see Chapter 2, Section 2.7.2.1):

- classification models
- advice models
- diagnostic models
- planning models.

The models built in this study belonged to the first three categories. The largest number were models which gave advice. Other features of the models in this study, which affected the construction process were:

- whether the number of conclusions was clearly limited or not
- the complexity of the conditions of the rules
- the complexity of the diagram
- whether there appeared to be any requirement to order the conclusions.

The characteristics of the models that were developed are summarised in Table 8.1.

8.2.2.1 The number of conclusions

The number of conclusions could vary widely from one to a large number. The range could be grouped into three main types:

- models with only one possible outcome, which was either true or false
- models with a small number of clearly identifiable possible outcomes
- models with a large number of possible conclusions.

Table 8.1 The characteristics of the models

Model	Type	Number of conclusions	Complexity of conditions	Complexity of Diagram	Ordered rules
Holidays	Advice	Limited by teacher	Complex (AND, OR, NOT)	Complex	Yes
Hotels	Advice	Limited by teacher	Fairly simple (AND & NOT)	Fairly simple	No
Conservation	Advice	Limited by time (could be many)	Fairly simple (AND only)	Simple	Yes
Communication	Advice	many	Fairly simple (AND only)	Fairly complex	No
Bones	Classification	many	Fairly simple (AND only)	Fairly complex	No
Rocks	Classification	Limited by time (could be many)	Fairly simple (AND only)	Fairly simple	No
Penny soccer	Advice	Limited by time (could be many)	Complex (AND, OR, NOT)	Simple	No
Football boots	Advice	Few (limited by nature)	Fairly simple (OR only)	Fairly simple	No
Motorbike faults	Diagnosis	Few (limited by nature)	Complex (AND, OR, NOT)	Simple	No
Choosing horse	Advice	Few (limited by nature)	Fairly simple (AND only)	Fairly simple	No
Baking faults	Diagnosis	Limited by time (could be many)	Simple (no logical operators)	Simple	No
Dog illness	Diagnosis	limited by nature	Complex (AND, OR, NOT)	Simple	No
John Barnes	Classification	two	Complex (AND, OR, NOT)	Simple	No
Going riding	Advice	Limited by time (could be many)	Fairly simple (AND only)	Fairly simple	Yes
Clothes	Advice	Limited by time (could be many)	Complex (AND, OR, NOT)	Fairly complex	No

Models with only one possible outcome would usually be relatively straightforward to construct. The task involved deciding which factors would affect the conclusion and in what combinations. The task could be well structured and the approach was top down. In this study two of the models were of this type, one, a model to decide whether or not your dog is ill was tackled as an introductory modelling exercise by two boys in School C. It is shown in Figure 8.28 and, although not complete, it made use of the logical rule structure and the pupils were able to tackle this with little help.

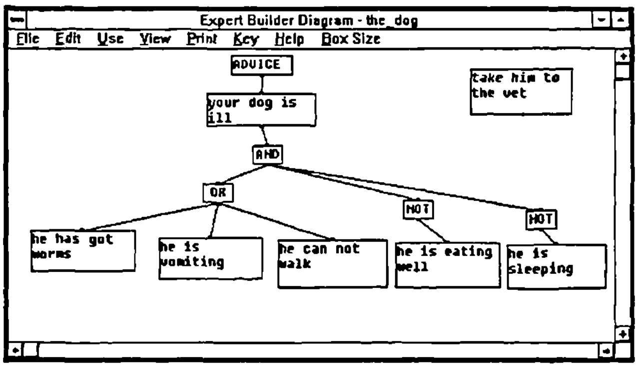

Figure 8.28 A first model, with only one possible outcome, built by two boys in School C

The other model, of this type (see Figure 8.29) was intended to identify the footballer, John Barnes. It was built by two boys from School C during about one hour of the session when they were allowed to construct models of their own choosing.

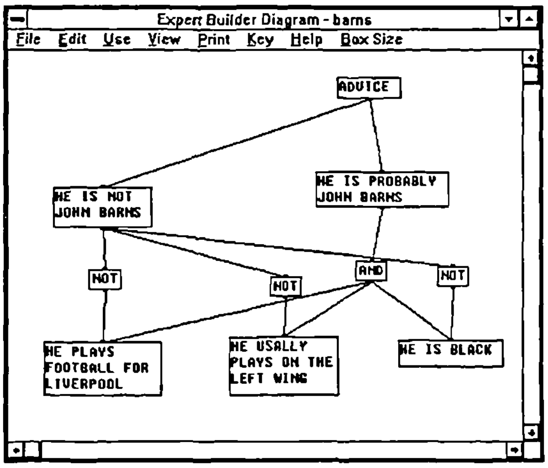

Figure 8.29 A model, with only one possible outcome, built by two boys in School C

This was a limited model but was complete and adequate for its purpose. The task was restricted and the boys, who had spent two one hour sessions on building the "rocks" model, were able to construct this without help.

It was possible to consider each conclusion individually and to build up a rule tree for each. Two of the tasks in this study were intrinsically of this type, "choosing a horse" and "selecting football boots". The latter is shown in Figure 8.18 and again was undertaken successfully as an introductory modelling task in School C. Several other tasks were tackled as though there were only a limited number of outcomes because the teacher limited the task. This applied to the "holidays" model and the "hotels" models built in School A.

Eight of the fifteen modelling tasks undertaken in this study involved models where there were a large number of possible outcomes. In these models it was generally difficult to identify all the conclusions at the outset of the modelling task. The strategy which modellers used to tackle such a task could dramatically affect their chances of success. In School B, one group, constructing models to advise on methods of communication, started by trying to create a clause box for each conclusion. Their model quickly became unwieldy and they needed help to rearrange it. In the second modelling exercise, in School B, the teacher encouraged the pupils to deal with one rule at a time and test their model regularly. This approach was used in the other modelling tasks where the models had a large number of possible outcomes. This strategy made the task of model construction more manageable but did not encourage a holistic approach to the problem.

8.2.2.2 The complexity of the conditions

Models with few conclusions could become more complicated if the combinations of conditions were more complex. When there are only a small number of advice clauses the elucidation of which combination of conditions leads to particular conclusions could be an interesting and manageable exercise. The modeller would first list the factors and then decide how they should be combined. This was true of five of the models in this study. The majority of the models consisted of simple rule structures with little use of logical operators. One of the models constructed during the initial study had a significantly more complex set of conditions. This model, shown in Figure 8.30, was based on the Battle of Hastings and was intended to predict which army would win a battle. The rules fire if two out of three of the conditions are true. This model was well structured. The pupils were able to work on it and had some idea of how the model worked but it is unlikely that they would have been able to create such a complex structure unaided. The teacher whose class built the model felt that the exercise of identifying the combinations was useful to undertake once with a class. But he also commented that a helpful addition to the software would be to be able to define operators that would return true if, for example, any two clauses out of a set were true. This suggestion was also made independently by a group of history teachers.

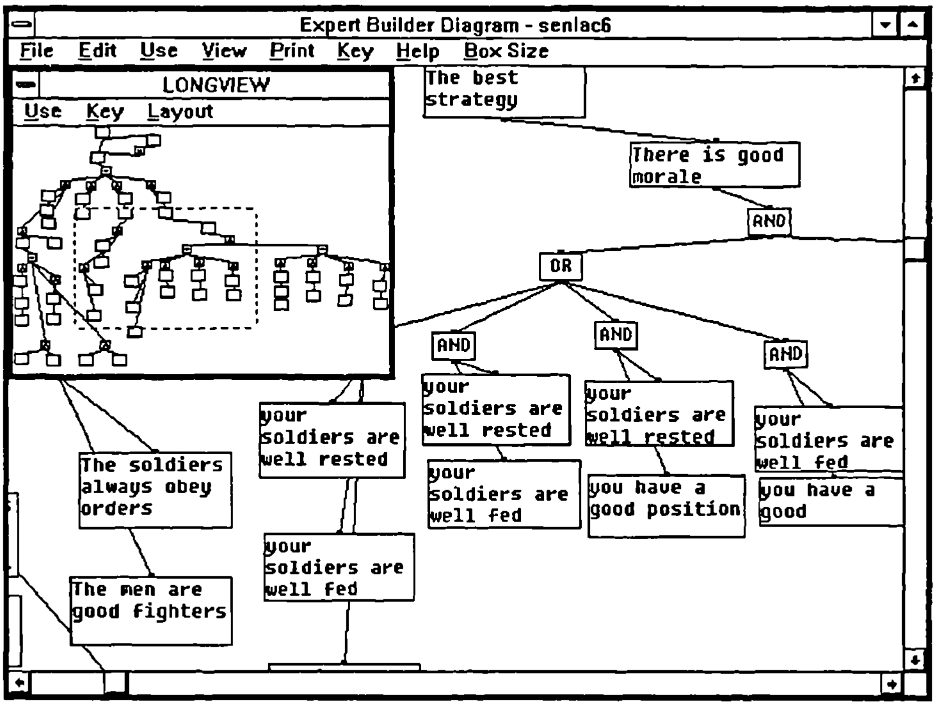

Figure 8.30 A model to predict which army would win a battle

Factors which affect the complexity of a diagram include:

- the number of cross links
- the number of levels of rules
- the complexity of the conditions
- how the diagram was laid out.

In this study all the participants were careful to lay out their diagrams as clearly as possible so that the layout did not add to the complexity of the diagram. Most of the models were relatively small and the diagrams were correspondingly fairly simple. Some of the diagrams were much larger than others in that they spread further horizontally but these diagrams were not continuously linked. They contained distinct rules that could be examined separately and they were therefore easy to interpret. Even the model of the "Battle of Hastings" constructed during the initial study, which superficially appeared quite complex, was fairly easy to understand when viewed as a whole. One impediment to interpreting the larger diagrams was that it was not possible to obtain a full-size printout of the whole diagram. This was partially overcome by providing a series of screen dumps that could be joined together but this facility was not available in the schools and so only some of the groups were provided with such printouts at certain times.

The models in this study have been classified into four groups according to how complex the diagram was to interpret (see Table 8.1). The main factor controlling this complexity was the number of cross links, e.g. the model advising people what to wear (Figure 8.18) looks fairly complex because cross links have been used rather than duplicating clauses. The "hotel" model shown in Figures 8.3 and 8.5 (page 196/197) shows how cross linking makes the diagram much more difficult to interpret. The pupils initially used one set of boxes for the conditions but when this resulted in a complex network the teacher advised them to use duplicate boxes and lay out each rule separately. The result was that the diagram, shown in Figure 8.5, was much easier to interpret.

Generally the pupils used fairly simple diagrams. One exception to this was in School A where the diagram for the "holiday" model became complex and difficult for most of the children to interpret. The teacher himself, who had directed the model to be built in this way also found it difficult to work with. This modelling task needed to be broken down into sub tasks in order to make it more manageable. The model was trying to advise:

- Whether you are able to have a holiday in the Far East
- Which country you might like to go to
- What preparations you would need to make.

The problem was made more complex because the modeller wanted to provide a sequence of pieces of advice and this aspect is discussed in the next section.

8.2.2.3 The order of conclusions

In three of the models the order of the conclusions was important. The modellers wanted to give a sequence of pieces of advice. It would be possible to achieve this by making use of the order of search used by the inference engine of left to right. This was not a feature that was emphasised when explaining the system to the teachers or pupils since expert system shells were not well suited to time based sequences. They were intended to draw conclusions based on conditions at a particular point in time. A major advantage of using an expert system shell for modelling was considered to be that the task is declarative rather than procedural. The dilemma arises because all expert system shells must have a search strategy and a starting point. If this was hidden from the user (s)he might not be able to control it fully but must have ways of influencing it, e.g. by assigning priorities to rules. In Expert Builder the simple left to right search strategy was not emphasised in the documentation but it was clearly apparent from the diagrammatic trace. At least one group of pupils in School A discovered this feature and they made use of it in constructing their conservation model. The builders of the other models in the study, which involved ordering of conclusions, were not fully aware of the left-right search strategy but they felt a need to present advice in a particular order.

In Expert Builder it was very easy to present a sequence of advice since it was a simple matter of arranging boxes from left to right on the screen. But it was a different type of modelling task from one concerned with analysing the conditions that affected a particular decision and in a structured learning situation it could distract from the task that was intended.

8.2.2.4 Summary of the nature of the models

The largest group of models in this study were advice-type models but classification and diagnostic models were also constructed. The models were also categorised according to the number of conclusions, the complexity of the conditions and the order of conclusions. Models with only one possible outcome or with a small number of clearly identifiable possible outcomes were successfully constructed, as introductory modelling exercises, by pupils in this study with little help. Several models with a large number of possible outcomes were constructed by pupils in this study, but many of these were a series of individual sub-models. Where the pupils tackled these models by building each sub-model and testing it they were successful but this method did not encourage a holistic approach to the problem.

Most of the models built by pupils in this study had simple rule structures and many made little use of logical operators. Where more complex models were built the teacher directed the structuring of the models.

Some of the pupils wanted to control the order of conclusions and at least one group found out for themselves how to do this. This presented a dilemma because it could encourage users to try to build models involving time-based sequences. This might lead to problems since Expert Builder did not incorporate any mechanism for dealing with temporal logic.

8.2.3 Interaction with the software

In the initial study, described in Chapter 6, a system interaction network was developed. This enabled a quick assessment and comparison between the groups to be made of the way the system was being used. This was useful for identifying problems with the user interface but the method required complete concentration while the activities were being observed. This meant that it was not possible to observe other aspects. Therefore it was decided this technique would only be used sparingly in the detailed study to allow a wider range of observations to be made. This was acceptable since the initial study had provided evidence that use of the interface was not a barrier to modelling.

Detailed records were therefore made of just two samples of the activities using the network designed in the initial study. One was during the early stages in School A when the pupils were being tutored to use the software and the second was in School B during the bones activity when the group had become fairly familiar with the software having spent about two hours using it. The results of this latter analysis are shown in

Figure 8.31 where they are compared with the analysis from the initial study. The relative amounts of use of most of the facilities was very similar in both exercises. In the "bones" activity more use was made of scrolling because the model was larger but less use was made of the testing tools. This was because the question tool only had to be selected once to test the model with one set of data and since the bones model was fairly large, running through the test with one set of data took considerable time. The model was actually tested twice during the hour session that was analysed. In both activities much use was made of the hand for moving boxes and this revealed the emphasis placed on laying out the model clearly.

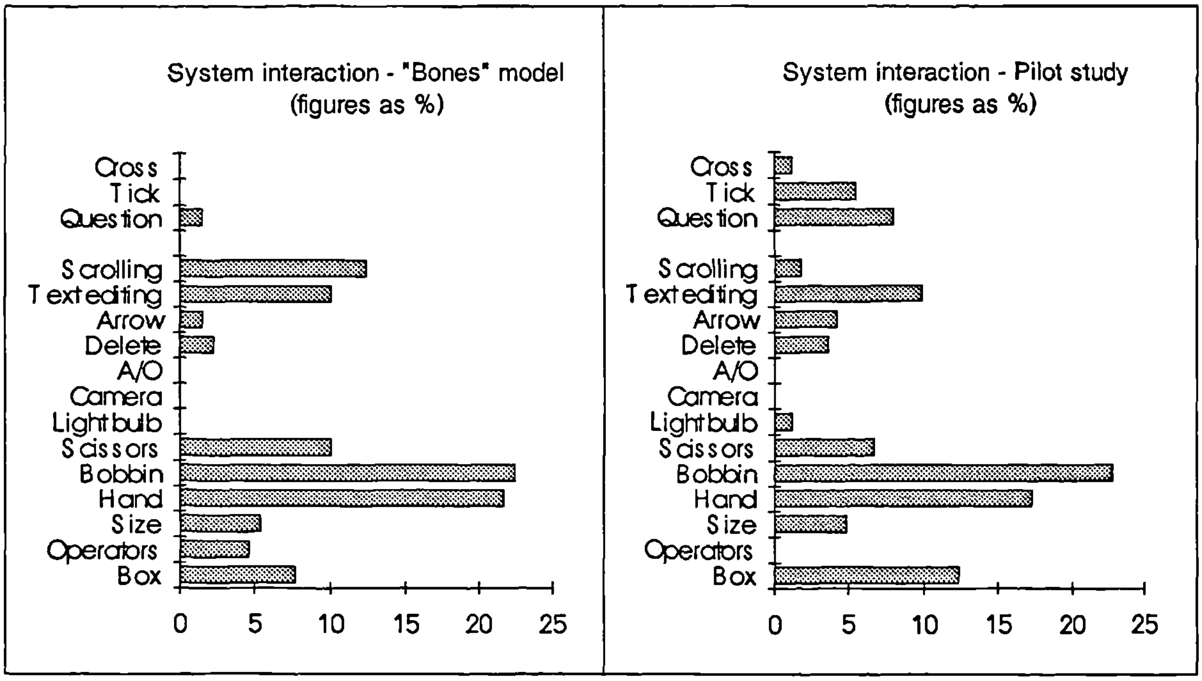

Figure 8.31 Results of the network analysis of two samples of the modelling activities

8.2.3.1 Problems with the user interface

During the hour analysed for the "bones" activity, only seven instances of problems with manipulating the user interface were recorded, compared with 44 during the initial study. Two of the problems were with the bobbin and five with the scissors. Although this was the only detailed data available, observations during the study confirmed that problems with manipulating the user interface were generally quickly overcome as pupils became familiar with the software. The only tools that continued to cause some problems were the scissors and the bobbin. These were not major problems. In the case of the bobbin, pupils simply released the mouse button too early or while the cursor was over the wrong place hence losing the thread. The new feature of highlighting the arrows when the bobbin was over each half of the box did make it easier for pupils to click in the correct part of the box. The method for using the scissors was fairly quickly learnt after pupils had initially tried to cut the threads. But they sometimes failed to delete the link because they didn't get the hotspot in the right place. Although pupils learnt to manipulate the scissors tool quite quickly this was still inadequate since its use was not intuitive. Initially most users attempted to cut the thread in the middle. Even when they had learnt the technique some still forgot on occasions. The software had been written in this way simply to speed up implementation. The sizing tool was not an ideal design since some pupils did not realise that it would jump to the lower right hand corner of a box, wherever it was clicked inside that box so they took pains to position it exactly in the corner. This caused frustration if they missed the edge of the box but it did not significantly affect the model building process. Some pupils were concerned to make the boxes particular shapes or to ensure that the text fitted the box without any gaps. The automatic sizing feature, whereby the box enlarged as the pupil typed, was valuable because it saved time that would have been spent re-sizing boxes. But this feature occasionally did not work properly, particularly if the user typed quickly, owing to some technical problems with Windows.

8.2.3.2 Interpreting system error messages

System error messages were only generated when the model was run by asking for advice or questioning and there was an error in the diagram. Only four instances of these were observed during this study because major mistakes in the logic were detected by the teacher or by the investigator and the pupils were then given help. On one occasion, described earlier, when the teacher attempted to connect NOTs illegally to more than one condition, he correctly interpreted the error message - "*There is a mistake in your rules : NOTS can only have one downward link*". When Dean and Keith tested their "bones" model they encountered error messages because they had accidentally created extra clause boxes or logical operators. They were shown by the investigator how to find the mistake the first time. But on subsequent occasions, although they knew how to find the mistake, they found searching for the problem difficult and frustrating and so they were given further help. This was clearly a feature of the system that needed to be improved.

8.2.4 Analysis of pupil talk

In the initial study, the "talk network", described in Chapter 6, was useful for identifying the amount and type of teacher intervention and the degree to which pupils were interacting and helping each other to learn to use the software. For the main study the network was developed further in order to characterise the types of verbal interaction relating to the use of the metaphor and the subject matter. This was significant compared with the pupils in the initial study who were still learning to use the software. In the main study, one group of pupils, in School B (Dean and Keith), was observed and recorded at a stage when they were fairly skilled at using the software and were able to focus on making use of the metaphor and considering the subject matter of the model. Another group of pupils (Emily, Ann and Christine) was observed and recorded when they had become reasonably efficient at using the tools but were still learning and experimenting with how to structure their model. The talk of these two groups was analysed using the network, which was refined further, to identify the types of questions and responses that the pupils were using. This analysis clarified aspects of the modelling process and the group interaction. The revised network was discussed and illustrated in Chapter 7 (Figure 7.1).

In School A there was a great deal of teacher direction during the sessions observed but in School B there were several sessions where groups were working more autonomously and the pupil talk could be characterised. During the earlier sessions where pupils were learning how to use the software, the majority of the talk was concerned with using the software. For example, an analysis of the talk during the session when Emily, Ann and Christine were constructing their model on methods of communication showed that only 15% was concerned with the subject matter, while

48% was concerned with using the system and 11% with structuring the model. An analysis of Dean and Keith's discussion, when they had become fairly familiar with using the software, showed a much higher percentage (47%) of talk relating to the subject matter of the model and 17% on structuring the model. Table 8.2 shows an analysis of the pupil talk concerned with building the model. The pupils were able to help each other to construct the model by suggesting how to perform actions and by instructing each other on what to do. The group of three girls, who were less confident in using the tools and were uncertain about how to structure the model, gave each other a lot of instructions about what to do and encouraged each other with comments such as "that's it". Dean and Keith were more adept at handling the tools and they made more suggestions and gave more explanations, particularly about how to structure the model. This analysis did support the view that by working cooperatively pupils were considering a greater range of possibilities by considering each other's suggestions and that they were helping each other to learn how to use the software and how to develop models.

Table 8.2 Talk concerned with modelling (figures as a percentage of the total)

Type of talk	Dean and Keith	Emily, Ann and Christine
Question to peer	7.5	4.7
Suggestion to peer	16.0	8.8
Question to teacher	4.4	4.1
Unsolicited fact	1.0	0.0
Fact - response to peer	2.2	5.8
Fact - response to teacher	1.4	0.6
Explanation to teacher	0.8	0.0
Explanation to peer	6.5	0.6
Instruction	9.5	28.0
Encouragement	1.2	13.0
Disagreement	4.6	3.5
Agreement	3.0	2.3

Table 8.3 shows an analysis of the talk about the subject matter in these two groups.

Emily, Ann and Christine were incorporating knowledge that they had obtained from class discussion and previous research. They were also considering whether different techniques of sending messages were over long or short distances. Their talk showed that they were making a lot of suggestions with which the other would either agree or disagree. Dean and Keith, on the other hand, were looking up information and structuring it into the model so there are more questions particularly ones that required one of them to find out particular information.

Table 8.3 Talk concerned with the subject matter (figures: percentage of the total talk)

Type of talk	Dean and Keith	Emily, Ann and Christine
Question to peer - recall	2.2	0.6
Question to peer - find out	6.7	0.6
Question to teacher	3.0	0.0
Unsolicited fact	3.4	2.3
Fact - response to peer	6.1	1.2
Fact - response to teacher	5.5	0.0
Explanation to teacher	0.6	0.0
Explanation to peer	1.0	0.6
Suggestion	0.8	4.7
Disagreement	1.0	1.7
Agreement	1.0	2.9
Summary	1.6	0.0

This analysis suggested that pupils did engage in discussion both about modelling and about the subject matter once they had become reasonably familiar with the software. The talk varied between the two groups. This variation could be attributed to differences in the ways in which they were working, i.e. Dean and Keith were researching information while building their model whereas Emily, Ann and Christine were using their existing knowledge. It is also possible that other factors such as personalities would influence the nature of the talk. This method of analysis did help to characterise the nature of the talk. In particular, it revealed that these pupils were questioning each other, making suggestions and responding with facts to each other's questions. This suggested that they were working cooperatively and this is considered more fully in the next section.

8.2.5 Cooperative working

In Chapter 3 the importance of pupils' working cooperatively in groups was discussed. Both Piaget (1978) and Vygotsky (1978), asserted the importance of social interaction in cognitive development. "Good primary practice" in England included group work (Alexander 1992). There was some evidence that group work with computers was beneficial for the learning of individual children (e.g. Sutherland and Hoyles (1987), Hoyles, et al. (1993) and Noreen Webb (1984)).

During this study pupils worked in groups of two or three. In most groups, one member manipulated the mouse and the another used the keyboard. When working in pairs both participants could be involved in building the model since one of the members was positioning and linking boxes and the other was typing the text. In this way Expert Builder encouraged cooperative working because this was the most efficient arrangement and all groups worked in this way without being instructed. Where there were three members of the group, the personalities and interests of the group members were important in determining whether they all took an active part in the work throughout the activity. In some groups the member who was not operating the equipment took a significant role in directing the others or thinking of ideas, e.g. see the talk of Emily, Ann and Christine in Table 8.2. In other groups the third member made little contribution and her/his attention was observed to wander from the work. In all the groups the pupils organised themselves to swap round at intervals. There were very few instances of pupils being deliberately uncooperative while working in these groups.

Expert Builder was not designed specifically to facilitate cooperative working although it was expected that pupils would work on a modelling task in groups. The task of building a model as a diagram in this environment meant that the activity was split almost equally between manipulating the mouse and typing text. In most of the groups there was relatively little explaining of their ideas but the emerging structure of their diagram revealed each other's intentions so that they did not need to talk when the model building was progressing in the way that they expected. In Schools A and B the discussions in the first stages of building the model were led by the teacher. In School C, the pupils did carry out the initial stages themselves but this was not recorded. During the later stages of the modelling activities the talk, such as that analysed in Tables 8.2 and 8.3, showed that the pupils were working together to structure the model and to use the software.

The screen view of the model helped the pupils to communicate their intentions by pointing at the structures. In the following conversation, for example, one of the boys was trying to create a slightly different rule structure from the simple two condition rule joined by an AND that they have been using, i.e. a rule with three conditions.

Dean	(Connects AND wrongly).
Keith	*It won't take that I don't think.*
Dean	*Why?*
Keith	*You're meant to have the AND up there* (pointing) *which goes to that* (pointing) *and that* (pointing). *I mean like and* (emphasised) - *there's only one bit coming off and it won't take that.*
Dean	*Yes well remember we're going to put this information. So we'll move this up (pointing) and move the AND up and then put the AND on to that (pointing) yes? because we need the AND on to that* (pointing) *don't we?*
Keith	*We ought to have the AND up there so it goes from there to there* (pointing).
Dean	*What do you mean?*
Keith	*Move that a bit and then get rid of that* (pointing on screen). *Move this up to about here* (pointing).
Dean	*No I was thinking we could move* (pause) *yes move this up to about here* (pointing) *and then put that AND to that* (pointing). *Do you see what I mean? Do you think it would work that way?*
Keith	*Probably. Can you have 3 things off an AND* (to the investigator).
Investigator	*Yes you can do.*

It is evident from this extract that actions are at least as important as spoken communication. During much of the interaction verbal explanations were very limited but the actions of structuring the diagram and typing in appropriate text enabled the pupils to communicate. Where pupils were working in pairs with one typing in the clause text while the other created the diagram structure a high level of non-verbal communication was involved. This corresponds with Noreen Webb's conclusion (Webb, 1984) who found that verbal interactions in the group did not affect interpreting and generating graphics programs and suggested that the group processes influencing learning were predominantly non-verbal. Noreen Webb suggested that the learning medium - the computer, was very different from other classroom learning media in that the strategies or approaches and results could be clearly seen by everyone because they appeared on the screen in a standardised fashion so pupils could learn from what other group members *did* as well as from what they *said*. This analysis was particularly relevant to Expert Builder where the model structure and its step by step execution were clearly shown on screen.

In summary, the design of Expert Builder did support cooperative working in pairs. It was also possible for some pupils to work effectively in groups of three where two manipulated the software and the third made suggestions or provided instruction. The success of this arrangement depended heavily on the personalities and interests of group members. The nature of the talk suggested that pupils were learning how to use the software and how to structure the model by interacting with each other.

8.2.6 Gender Effects

The group membership in all three schools was decided by the teachers who based their decisions on their knowledge of how well particular children worked together. During the earlier activities in School A, when the models were built as a class activity, there were no fixed groups. The teacher set two or three children to work on the model and then sometimes swapped another child into the group during the session. Sometimes the groups were single sex and at other times they were mixed. During the conservation activity there were four distinct groups with the following combinations of boys and girls:

Group 1 two girls and one boy

Group 2 one girl and two boys

Group 3 two girls

Group 4 one girl and two boys.

In School B the five groups contained the following combinations of boys and girls:

Group 1 3 girls

Group 2 two boys

Group 3 two boys

Group 4 two girls

Group 5 two girls and one boy.

In School C the initial groupings were six groups of two girls and six groups of two boys. Subsequently, for the rocks exercise, there were three groups of two boys and three groups of two girls. In the final activity pupils were able to choose their partners. They chose to work in groups of two or three or individually. The membership of some of the groups changed during the morning. There were no groups of mixed gender.

In Schools A and B no general differences were observed between the boys and the girls in respect of their enthusiasm for and interest in the modelling tasks, or their skill with the software. In School C, however, a higher proportion of the boys were quite proficient at using the computer, particularly manipulating the mouse. These boys showed confidence and were willing to experiment so that they became adept at using the package more quickly than the girls. It was suggested, by the teacher, that this particular class was unusual in that it contained a higher proportion of able boys. A contributory factor was that the computer was used very little for classroom work but was available during lunch hours and the boys used it to play games whereas the girls did not.

8.2.7 Teacher intervention

The teaching strategies in the three schools, which were described earlier in this chapter, differed in that the approach in Schools B and C was less directed than in School A. But in both Schools A and B there were sessions when the pupils were building the models in groups and the teacher was intervening when he considered that intervention was necessary or helpful. This intervention was considered in relation to three aspects of the modelling activities:

1 manipulating the software

2 structuring the model

3 selecting and structuring knowledge

Intervention concerned with manipulating the software, e.g. which tool to use, generally involved immediate correction or instruction. If either teacher observed a pupil using the software inefficiently he immediately told her/him the better way of working or at least suggested an alternative way of working. The teachers appeared to believe that the pupil was deriving no benefit from learning by experience and should be corrected. They were both slightly more tentative in their intervention concerning inappropriate structuring of the model, e.g. if the pupil had created a rule upside down or failed to connect an advice box. They usually intervened by asking the pupils to examine the part of the diagram carefully or asked them to look for a mistake. The nature of the intervention concerned with selecting and structuring knowledge showed some variation between the two teachers. The teacher in School A, had fairly definite expectations of what knowledge he expected the model to contain and he intervened by asking a series of fairly directed questions. The teacher in School B had a more open ended view of the task. He intervened when he noticed a problem in the knowledge content or the arrangement of the knowledge by suggesting that they should look carefully at something or that they should test their model in a particular way.

Expert Builder gave some feedback to pupils about whether their model was working as they intended but they sometimes needed help to interpret the feedback. In particular, the modeller sometimes needed to be introduced to further features of the system, when the model didn't behave as expected. Pupils discovered some of these features for themselves but made faster progress when they asked the teacher how to do something and it was demonstrated or explained to them. The teacher could assess the situation quickly and intervene with advice or instruction because the problem was clearly visible on the screen.

Discussions with the teachers suggested that they both intended that the activities should consolidate pupils' knowledge and/or encourage them to research more information to extend their knowledge. During the activity on energy conservation in School A, for example, the emphasis was on remembering and restructuring knowledge that had been researched and discussed. Teacher intervention was concerned with encouraging the pupils to link together relevant knowledge. For example in the extract below, the teacher tries to encourage the pupils to provide deeper explanations for the clause "it is important to care about energy":

Rose	*because if we use* (reading part of explanation already written) *there will be none left and we wouldn't survive without it.*
Catherine	*We would survive with difficulty.*
Rose	*There would be none left and we would not survive very well.*
Catherine	*How do you spell survive.*
Rose	*S U.*
Catherine	*S U.*
Rose	*R V I V E. Not very well. Bottom your fingers on it just about* (Catherine trying to find keys) *not survive. Yeah.*
Catherine	*What else? Luke?*
Rose	*I dunno* (pause) *because if we use it all up there will be none left and we wouldn't survive very well at all. No, that makes it sound like a book doesn't it. (pause).*
Teacher	*What's the it?*
Rose	*Energy.*
Teacher	*Would be better to say so -.*
Rose	*Yeah.*
Teacher	*-from an English point of view, a language point of view (Catherine corrects) There's an extra space there you can get rid of. Because if we use all the energy there will be none left and we will not survive very well. Is there anything else that you want to put in there.*
Rose	*No.*
Catherine	*No.*
Teacher	*Is that all there is? Sure?*
Rose	*Well um* (pause).
Rose	*Um we will not survive very well. There will be no lights.*
Teacher	*Yes. You are asking the question - is it true that it is important to care about energy and you will want the person to say: "yes it is true that we should care about energy". Now what we're asking you is why.*
Catherine	*because er.*
Teacher	*So far you've said - because if we use it all up and there's none left we wouldn't survive very well.*
Catherine	*Right then.*
Teacher	*Is there anything else that you need to consider?*
Catherine	*Er* (pause).
Teacher	*Would we survive at all if the energy went?*
Rose	*No.*
Luke	*No.*
Teacher	*No so you're actually talking about the future of the human race really.*
Rose	*Cos we wouldn't have any more so.*

They went on to change the explanation and the teacher prompted them to think about where the energy comes from and goes to. The activity was therefore providing a focus for the teacher to try to consolidate some of their understanding of energy.

In School B there was more emphasis on pupils doing their own research and deciding what they should include, within set limits, in their models. But the teacher also intervened to encourage pupils to extend their knowledge and to remember ideas that had been discussed previously. For example, in the following intervention the teacher encourages them to think about other aspects of bones in addition to their positions.

Teacher	*A lot of these you're giving the connections all the time, which is fine. It's a way of identifying where the bone is but do you remember what we said about the cranium, for example, - what its job was?*
Dean	*To protect the brain.*
Teacher	*Yes I wonder if there's any other bones* (pause).
Dean	*That protect?*
Teacher	*Well not.* (pause) *yes could be to protect. Can you think of any other set of bones that protect major organs?*
Dean	*Does the shoulder blade protect something?*
Teacher	*What?*
Dean	*That bit there* (pointing to collar bone).
Teacher	*Yes that's a bone but the cranium protects the brain yes?*
Dean	*Yes.*
Teacher	*Which is an organ. What are the other major organs in the body?*
Dean	*Oh the ribs protect the heart.*
Teacher	*That's right anything else that they protect? You've got the heart in there. Anything else?*
Dean	*Lungs.*
Teacher	*Lungs. Now what about in and around here? What's down this end of the body?* (pointing to abdomen on the model skeleton).
Dean	*Is it the stomach?*
Teacher	*It's the stomach in there. So there is the protective element there's also the liver and kidneys down here* (pointing to skeleton model), *which get some protection from the pelvis, so perhaps if you are looking for other ways of identifying bones you might look at what they protect.*

In Schools A and B the teachers appeared to spend approximately the same amount of time with the group working on the modelling activity as with groups involved in other activities. In addition, in the early stages of the activities when the pupils were learning the basics of manipulating the software, the investigator responded to their requests for assistance. This differed from the findings of Eraut and Hoyles (1988) who reported that generally teachers do not intervene when pupils are working at a computer, because they work on them for long periods without any signs of boredom or disturbance and this frees the teacher to attend to other pupils.

In summary, teacher intervention was important in both schools for helping pupils to learn how to use the software and how to construct models and for encouraging pupils to consolidate their knowledge. The development of knowledge and understanding is also discussed in the next section.

8.2.8 Development of knowledge and understanding

In the previous section, the way in which the pupils were encouraged to consolidate their knowledge and understanding by the teacher was discussed. In all three schools pupils were observed searching for information in books and the modelling activity was providing the stimulus. The modelling activity promoted pupils' learning and understanding of knowledge by increasing motivation and creating the need to select and structure the knowledge into the model. A similar effect might be achieved by a paper based activity, where selecting and structuring the knowledge was required, e.g. making a poster, producing an information leaflet. The main difference between such activities and the computer based modelling activity was that the latter provided feedback to the pupils. The models could be run and they produced different output depending on the input so the pupils were encouraged to check the information that they had input and to examine their reasoning.

It was not possible to determine, from this research, whether these modelling activities have enhanced pupils' learning of the subject matter more than other learning methods. There was evidence of long periods of concentrated effort but, except for Keith and Dean, who became very familiar with the software facilities that they needed for their model, most of the effort was directed towards structuring the model and using the software. Papert (1984) suggested that "*fluency in programming provides an opportunity for teachers to teach in new ways and for students to learn in new ways*" and he suggested that this was sufficient justification for learning programming. In a similar way, if qualitative modelling could provide new teaching and learning opportunities and at the same time introduce pupils to the skills, processes and limitations of modelling this would be sufficient justification for its use. One study by Harel and Papert (1990), which did provide evidence for enhancement of pupils' learning of fractions, involved pupils in designing and writing software using LogoWriter over a period of about 70 hours. In this study most of the groups had no more than four hours working on their models. Even Dean and Keith who produced the "bones" model spent a maximum of seven hours on modelling.

8.3 Results and discussion of test of competency

The main part of the study focused on qualitative modelling integrated within the normal curriculum and classroom setting. To support this a structured test was devised to measure the pupils' levels of competence in using Expert Builder, to identify the difficulties that they experienced and to try to clarify pupils' mental models of the software. The basis of this test and how it was administered was described in Chapter 7 and the test is included in Appendix 4.

8.3.1 Exercise 1

This exercise was designed to investigate pupils' use of the user interface, their mental models of the basic rule structure and whether they were able to create a simple rule by following a pattern. The results of Exercise 1 are summarised in Tables 8.4 and 8.5 and are discussed in the rest of this section.

8.3.1.1 Manipulating the interface

It is clear from Table 8.4 that all the pupils could manipulate the tools. The only exception to this was that three pupils needed several attempts at linking boxes. This result accorded with previous observations and the results of the questionnaire survey, described in Chapter 6, which showed that the interface was generally easy to use. This exercise did not involve using the scissors which had already been identified as causing some problems in the initial study. Several pupils were very slow at typing and finding the keys.

Table 8.4 Manipulating the interface - results of Exercise 1

Manipulation	Total correct	Total answers	% correct
Task 1 Get the question mark tool (1st click)	22	22	100
Task 3 Click on advice	22	22	100
Task 5a Box tool (tool use)	22	22	100
Task 6 Create box (tool use)	22	22	100
Task 10 Box-box link made (linking)	22	22	100
Task 11 advice -box link made (linking)	22	22	100

8.3.1.2 Understanding the inference mechanism for a simple rule

The first exercise involved predicting how the system would work, i.e. how the inference mechanism would deal with one simple rule (shown in Figure 8.32).

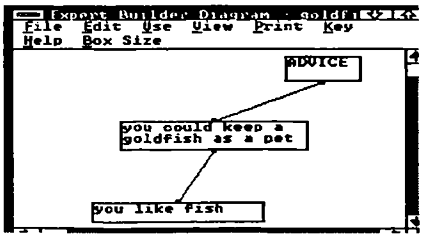

Figure 8.32 The simple rule used in Exercise 1

To complete this task pupils needed to understand the nature of a rule, i.e. that if a premise was true, a conclusion that was linked to it, by a simple thread, would also be true. In addition they needed to understand the basis of the inference mechanism, i.e. that the system would need to check the status of the premise by asking the question. Relatively few of the pupils (four out of 22) understood both of these ideas. This was a minimum requirement to be able to construct models using this environment as discussed in Chapter 3 (Section 3.4). As shown in Table 8.5 three of these pupils were among the six pupils who were able to build a correctly structured rule when they did Exercise 3. The rest of these six pupils had known the structure of a rule although they had not shown understanding of the inference mechanism. Two out of the four pupils, who showed understanding of the rule structure and the inference mechanism, had demonstrated that they were able to structure rules in an appropriate way when they worked on the "bones" and "communication" activities (see section 8.1.2). The other two had only worked on models where they were heavily directed by the teacher.

Table 8.5 Understanding the inference mechanism

Pupil name	Understand that if the premise is true the conclusion is true	Understand basis of the inference mechanism	Construct simple rule (Task 5)	Model in Exercise 3 - correct basic rule structure	Previous successful model construction in a group with some help
Vivian	√	x	√	√	√
Mark	√	√	√	√	no opportunity
Simon	√	√	√	√	no opportunity
Luke	√	x	√	√	√
Philip	x	x	√	x	√
Rose	√	x	√	x	√
Rena	x	x	x	x	√
Ben	x	x	√	x	√
Laura	x	√	x	x	√
George	√	x	x	x	no opportunity
Catherine	x	√	x	x	√
Harriet	x	x	x	x	x
Marion	x	x	√	x	x
Adrian	x	x	√	-	x
Carla	x	x	x	-	x
Emily	x	x	√	x	√
Christine	√	√	√	x	√
Anthony	x	x	√	x	√
James	x	x	√	x	√
Angela	x	x	√	x	x
Dean	√	x	√	√	√
Keith	√	√	√	√	√
Total	9	6	16		

The pupils who were unable to predict either the question or the advice statement of the model shown in Figure 8.32 were not using any general mental model of how the system worked. One girl expected the system to produce all sorts of questions relating to fish even though it was explained to her that what she could see on the screen was all there was in the model. She had retained a mental model of computers as being "clever" despite having used the computer for developing her own models, an exercise that generally convinces pupils that the computers and the models are only as good as the people who program them. This belief in computers being "clever", which had been observed during the Modus feasibility study (Webb, 1988) was not evidenced in any of the answers given by other pupils.

8.3.1.3 Identifying and following a pattern

Exercise 1 required the pupils to explore a simple rule and then go on to create their own rule based on the same pattern. The first rule was left on the screen so that they could use it as a template. Discussions with expert modellers in industry had suggested that most of them start building models by considering constructions that they have worked with previously and try to find one whose behaviour matches that which they are trying to model. Therefore the ability to identify similarity and adapt a template is an important modelling skill. A recognition of the value of looking for such similarities could also be important. As shown in Table 8.5, sixteen of the pupils (73%) created the correct rule structure, the other six did not see the similarity with what they had just been doing.

The pupil, who had previously expected the system to ask all sorts of different questions, tried to create a more complex rule structure and so had learned little from carrying out the first part of the exercise. Another pupil created the structure upside down so that her diagram appeared as in Figure 8.33.

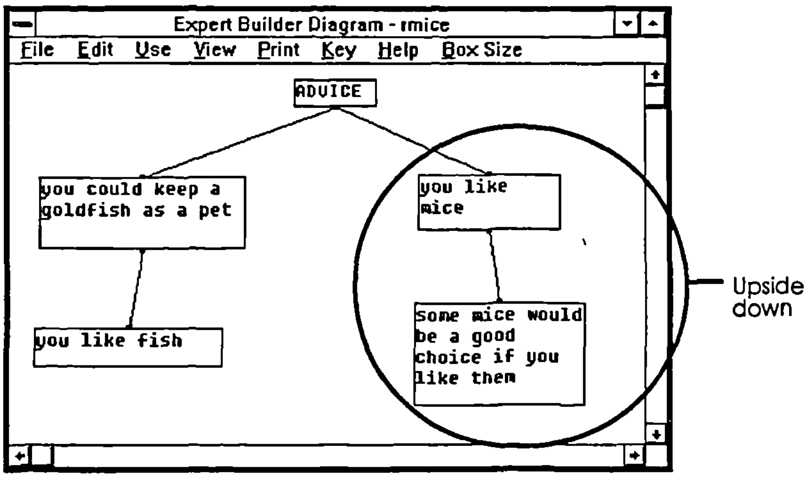

Figure 8.33 The model for Exercise 1 showing an upside down rule structure created by a pupil

Two of the pupils inserted an OR in the structure (see Figure 8.34), as though an OR was necessary to denote an alternative piece of advice. Apart from the OR their structure was actually correct. This misinterpretation of the use of logical operators was also observed on two occasions during the main part of the study.

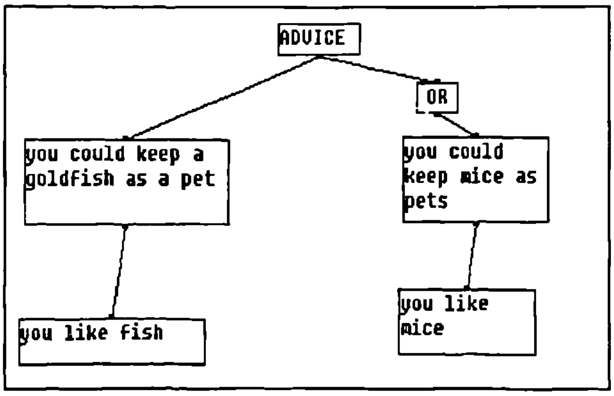

Figure 8.34 A model using OR incorrectly

8.3.2 Exercise 2

This was concerned mainly with pupils' understanding of the meanings of the logical operators. The results of Exercise 2 are summarised in Table 8.6 and are discussed in subsequent subsections.

Table 8.6. Results of Exercise 2

Pupil name	Mouse model - understand use of AND (simple rule)	Rabbit model - understand use of AND & OR (more complex rule)	Explained rabbit model by logic (l) or content (c)	Task 14 ABCDE model	Task 15 ABCDEF model	Task 16 Z model
Vivian	√	√	l	√	-	-
Mark	√	√	c	√	x	x
Simon	√	√	c	√	-	-
Luke	√	x	c	√	√	√
Philip	√	x	c	x	x	-
Rose	√	x	c	√	x	x
Rena	√	√	c	x	x	x
Ben	√	x	c	x	x	-
Laura	x	x	c	√	x	x
George	√	x	c	x	√	√
Catherine	√	x	c	√	√	x
Harriet	x	√	c	x	x	x
Marion	√	√	c	√	x	x
Adrian	x	x	c	√	√	√
Carla	x	x	c	√	x	x
Emily	√	x	c	x	x	x
Christine	√	√	l	√	x	x
Anthony	√	√	l	√	x	√
James	√	√	l	√	√	√
Angela	x	x	c	x	√	√
Dean	x	√	c	√	x	x
Keith	√	x	c	x	√	√
Total	16	10		14	7	7

8.3.2.1 Pupils' understanding of the meanings of the logical operators.

The mouse model (see Figure 8.35) was used to test pupils' understanding of the logical operator, AND. Only eight out of the 22 pupils successfully ticked both boxes attached to the AND at their first attempt. However, as can be seen in Table 8.6, further attempts enabled 16 to succeed.

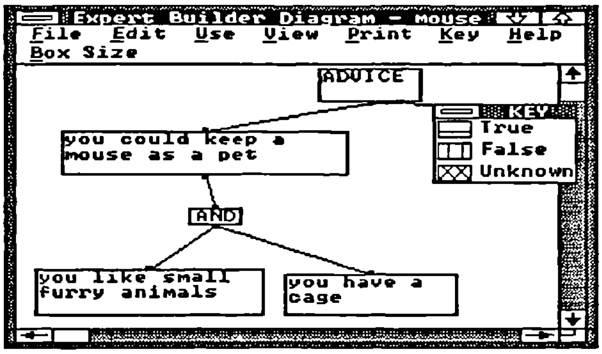

Figure 8.35 The rule containing AND used in Exercise 2

All the pupils read the text in the clauses fairly carefully suggesting that they were not simply examining the structure of the diagram but were interpreting the subject matter. A few pupils actually stated in their explanation that it wasn't really necessary to have a cage for the mouse. Only one of the pupils justified his answer by specifically referring to the AND on the diagram whereas 19 of the pupils justified their answers by reasoning about the subject matter. At this stage they had realised that it was necessary to tick both boxes and some of them were clearly explaining the logic of the model rather than their own logic. Nine of the pupils were able to explain the effect of changing the AND to OR and four of these had previously failed to tick both boxes. Even pupils who had understood the logical nature of the modelling environment interpreted the model by using their own reasoning even if this conflicted with that shown on the diagram. This is consistent with the findings of Henle (1962) who provided evidence that reasoning errors were due to subjects interpreting problems in a way not intended by the problem setter. They might fail to accept the logical task or change the logic by introducing their own prior knowledge or reasoning.

8.3.2.2 Pupils' reasoning

The more complex "rabbit" model used for Task 13 provided further evidence that pupils were using their own reasoning rather than interpreting that provided on the diagram. Again most of the pupils carefully read the text and ticked the ones that they felt to be necessary, ignoring the structure of the diagram. As can be seen in Table 8.6, the majority of the pupils justified their answer by referring to the content of the diagram rather than its logical structure.

Task 14 required pupils to interpret the diagram rather than use their own reasoning since there was no subject or other text in the boxes, only a structure (see Figure 8.36) which was identical to that of the rabbit model.

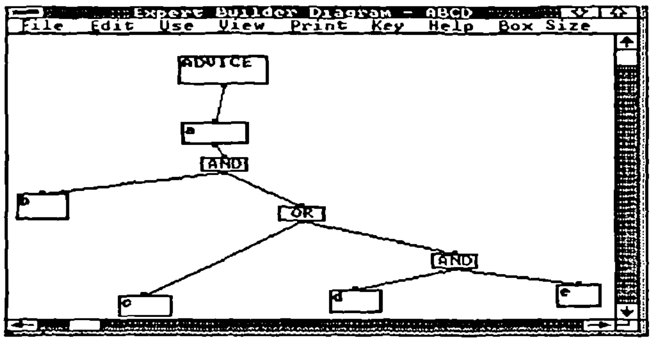

Figure 8.36 The model for Task 14

As can be seen from Table 8.6 some pupils who had been confused by the "rabbit" model completed this task successfully. This suggests that pupils are more successful at interpreting the model when they are not distracted by subject matter to which they can apply their own reasoning.

8.3.2.3 Dealing with more complex rule structures

Some of the pupils were asked to interpret more complex rule structures in Tasks 15 and 16. This task showed, as expected, that the majority of pupils had not fully understood the nature of the branching. However, as can be seen in Table 8.6, some of the pupils were able to deal with these tasks and showed good understanding of the structure of the diagram. Two of the pupils did ask, during the test, whether it was possible to tick both boxes connected to an OR, which showed that they were thinking about the significance of the logical operators.

The results of this test are consistent with the practical logical reasoning elucidated by Braine and Rumain and discussed in Chapter 3 (Section 3.6.3). Most of the pupils started from their own prior knowledge, when they were interpreting the models, and they ignored the logical structure of the diagram. When the subject matter was removed some pupils were able to deal with the basic structure that was based on formal logic.

8.3.3 Exercise 3

This was an open-ended modelling activity intended to determine to what extent pupils could make use of the modelling environment to construct their own models, given a particular scenario based on choosing where to shop. It was also intended to identify their problems. The details of how the activity was conducted are given in Chapter 7.

8.3.3.1 Initial ideas

The initial discussion, which was a brief role playing exercise, served to focus pupils' thoughts on the problem and they began to suggest advice that might be needed. None of the pupils who was acting as expert was able to give a coherent and comprehensive set of advice. Most of the pupils who were trying to imagine that they had come from another planet found some difficulty in thinking of themselves in that situation. For this part of the exercise to be a useful learning experience on its own it would have been necessary to spend more time setting the scene. In this exercise it was limited to about five minutes and served to illuminate pupils' initial thoughts on the problem. Some of the pupils needed some prompting in order to get started and they were reminded of the situation as described on the card.

8.3.3.2 Manipulating the interface

As noted during previous exercises, nearly all the pupils were now quite competent in selecting and manipulating the tools so this did not present a barrier to their progress. Several of the pupils made rather slow progress as a result of their slow typing.

8.3.3.3 How do they start to construct the computer model?

When the pupils switched from the role playing exercise to building the computer model they had to focus on how to make the metaphor work for them. Up to this point they had been encouraged to give advice and ask questions and this may have influenced their approach. The approaches that they used could be described in four categories as shown in Table 8.7 and illustrated in Figure 8.37.

Table 8.7 Initial approaches to building models

Approach	Number of groups adopting this approach
a) Advice statements only	8
b) Full rules with advice box, advice clauses and conditions	6
c) Questions and answers	2
d) A series of questions	1

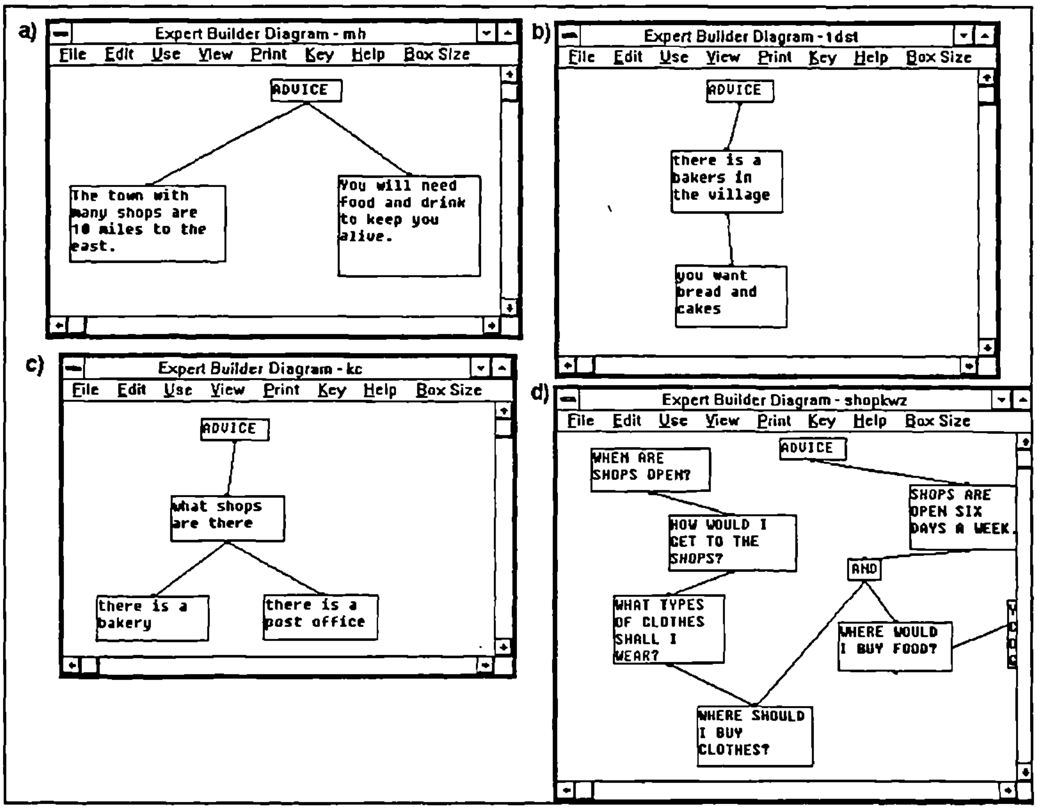

Figure 8.37 Examples of the four types of approach listed in Table 8.7

Of the 11 groups who undertook this Exercise, six went straight in with no questioning or discussion about how to structure their models whereas five showed some evidence of thinking about the modelling metaphor. None of them made any real attempt to plan their model but this was not unexpected since they had not been encouraged to do so during previous work.

The six groups, who went straight in, all adopted approach 1 so they had grasped the idea that they could put a statement in a box and link it to an advice box and it would be given as advice. The following extract of the transcript illustrates a typical conversation at the start:

Catherine	*Get some boxes*
Luke	*Make an advice box first* (makes advice box). *You need to type there?* (placing a box).
Catherine	*Alright.*
Catherine	*Say you go to the post office you could put the post office up there*
Luke	*Right where shall we put it then right*
Catherine	*Go to the supermarket to get some food*
Luke	*There?*
Catherine	*All right then.*
Luke	(types).
Catherine	*Go to the supermarket - to buy some food. Put a capital letter there. Do you think she's got a car?*
Luke	*No.*
Catherine	*Right tell her where a garage is. Could say where the bus station is?*
Luke	*Well you write something.*
Catherine	*You've got the keyboard. All right then what do we do?*
Catherine	*Go to the shops to get - er - to buy some clothes - er - yes what else can she buy.*
Luke	*clothes.*

In this talk there is an underlying assumption, which neither of them question, that the model simply requires a series of pieces of advice.

Laura and Ben showed a little thought about what they were doing and their discussion illustrates that their view was of a series of pieces of advice. They were searching for a starting point and they expressed conditional rules.

Laura	*Well if she wanted.*
Ben	*Money?*
Laura	*Money - she could go to the post office or if she wanted bread she could go to the bakers and if she needs fruit - she could go up to the town and buy things she needed.*

Ben	*Or supermarket.*
Laura	*Or supermarket.*
Ben	*Where's the box - is that a box?*
Laura	(Gets the box).
Ben	*OK, one box will do for now and we need an advice box as well.*
Laura	*Which is advice?*
Ben	*I think it's that one.*
Laura	*Is it? Yes,* (creates advice box). *We need to know what we're going to write in there now. We want to see - er -. We can advise her to go .... first of all we'll advise her to go.*
Ben	*To get a.*
Laura	*To walk down the street to the post office and get some money.*
Ben	*Yes.*
Laura	(Types) *Get some money from the Right.*
Ben	*Get some money from the post office. Full stop.*
Laura	*Right, that's that one.*
Ben	*So how do you get there?*
Laura	*Um. Need another box* (creates box).
Ben	*Not there.*
Laura	*Well we can move it.* (moves box down) *And we need to write So get some money from the post office. So she's got some money. Catch a bus to the supermarket?*

Mark and George, were thinking about how they could structure their model but they had not distinguished between the conditions and conclusions:

Mark	*So I've got to tell you what I need um clothes. Where would I get them from?*
George	*Er that would be Mothercare.*
Mark	*No where else would you get them?*
George	*C&A, John Lewis.*
Mark	*John Lewis, Fosters - So I need some clothes. How are we going to do that? We'll want some boxes won't we?*
George	*Yeah first of all put an Advice box.*
Mark	*Yeah get a question mark.*
George	*Is it a question mark?* (To Investigator).
Investigator	*What do you want to do?*
Mark	*Get an advice box.*
Investigator	*It's the light bulb.*
George	*Where's the light bulb.* (creates an advice box).
Mark	*Get a box.*
George	(Creates 4 boxes) *One there, one there, one there and one there.*
Mark	*That'll do for the minute.*
George	*What about an AND and OR?*
Mark	*Oh yes AND* (George gets AND tool).
George	*It'll be there won't it? It won't be there. The OR will be down there because those two boxes will be for the OR. OR you could get it from somewhere else.*
Mark	*Oh yes. Get the hand so you can move the box down there. That'll be there. Right so if you put that box down there* (George moves it) *So if you put a box there* (George does) *That's it right so if we put you will need clothes. So you could put*

	two places. No we've got this wrong. So if we put a shop there and a shop there and we connected those two and those two, we went down there and you could go to Fosters and say put C&A up there. You could go to BHS, Mothercare and stuff like that.
George	*Mmm.*

One group referred back to the "mouse model" when asking the author what they had to do showing that they were thinking about how to tackle this task by reference to a previous model.

The approach that the pupils adopted when starting to build their models gives some indication of the adequacy of their mental models of the modelling metaphor for tackling this new problem. However it was not possible to generalise about the adequacy of their understanding of the modelling metaphor for tackling all new problems as the nature of the new task could influence the pupils' ability to make use of the modelling metaphor. There was, for example, evidence in School C during the first part of the study, that pupils were better able to make use of the modelling metaphor when undertaking a task that they had set themselves where they were very familiar with the subject matter. Mental models are constructed at a particular instant in time to solve a problem and they are short lived. Of the 17 groups who tackled this Exercise, six started by defining full rules, and had therefore adopted an adequate mental model of the modelling metaphor in relation to this particular problem. Nearly half of the groups started by creating advice statements only. This suggested that they had focused on a limited subset of the modelling metaphor that would not be adequate for constructing their models. The nature of the problem, as presented, fostered this error by focusing attention on the need to provide advice to Jane rather than emphasising the importance of different conditions requiring different advice.

8.3.3.4 Making use of the metaphor

Of the 17 groups who attempted Exercise 3, four succeeded, without help, in making appropriate use of the metaphor to create models that worked. Two of these created models with one level of advice. Dean and Keith's model (see Figure 8.38) consists of a large number of simple rules with no logical operators. This was the pair that had created the "bones" model successfully. Once they had successfully created one such rule they were content with this structure and concentrated on making it as comprehensive as possible.

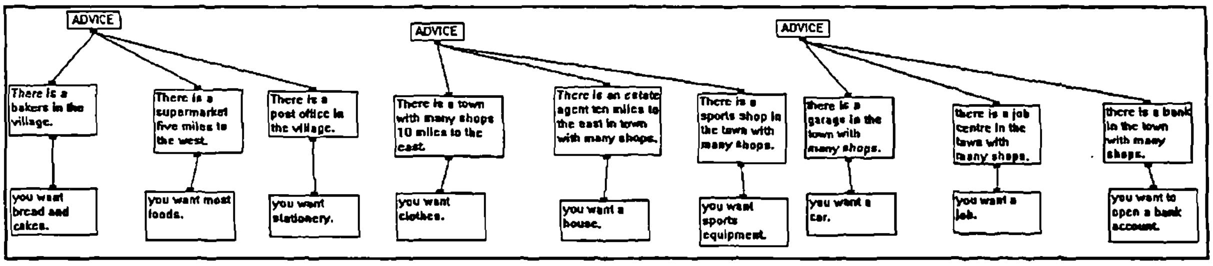

Figure 8.38 Dean and Keith's model consisting of many simple rules with no logical operators

Their discussion, part of which is given below, shows that they were able to consider what they wanted their model to do and how to make use of the modelling metaphor to achieve their aims. They were both using an accurate mental model of at least part of the modelling metaphor in that they were aware of the rule structure where a conclusion depends on one condition and how to structure the diagram to achieve that. They created a very simple logical structure with no logical operators although they had previously used these successfully. They apparently felt that this simple structure was adequate for their model.

Dean	*There is a supermarket - yes we can have er - well I'll try that then (types in) whoops - delete that - 5 miles to the west.*
Keith	*You can get most things in the supermarket.*
Dean	(types).
Dean	*Oh no but then it will ask - "is it true that you can get most foods in the supermarket?" won't it.*
Keith	*You want most foods.*
Dean	*Yes* (changes it to you want most foods then selects ?).
Keith	*Hang on it isn't connected up.*
Dean	*Oh no.*
Keith	*Cotton.*
Dean	(Gets cotton and connects then tests).
Keith	*You want bread and cakes* (reading) *- yes - there is a bakers in the village - More advice.*
Dean	*Is it true that you want most foods* (reading) *- yes - there is a supermarket 5 miles to the west.*
Keith	*Yes we've got that.*
Dean	*Now what?* (rereads the instruction card).
Dean	*I know what we could do now - about the - shall we do one on the post office - if you want um.*
Keith	*Stamps.*

Dean	*Well if you want to post any letters or to buy stamps.*
Keith	*Well - supermarket sells just about everything.*
Dean	*What about letters?*
Keith	*Um.*
Dean	*Shall we try that then?*
Keith	*Well try there is a post office in the village.*
Dean	*Yes* (types there is a post office) *down the road?*
Keith	*In the village - she might not know where the road is.*
Dean	*Yes* (types).
Keith	*You want --.*
Dean	*You want to post letters and buy stamps.*
Keith	*You want stationery.*
Dean	*If you want stationery.*
Keith	*No you have to put you want stationery.*

Throughout the study, this particular pair of pupils interacted very well, bouncing ideas off each other and thinking ahead to how the model would work. There was a very high level of concentration even though they worked for about an hour at a time. It is interesting to note that when Keith and Dean's rule structure is converted into the "conclusion if premise" structure the rules don't make logical sense although they are typical of everyday speech:-

there is a bakers in the village if you want bread and cakes

This was an example of where the diagrammatic structure allows more flexibility than textual rules.

Vivian saw the problem as a logistical one of deciding which place to go to shop and hence she struggled to create a more complex and sophisticated model (Figure 8.39).

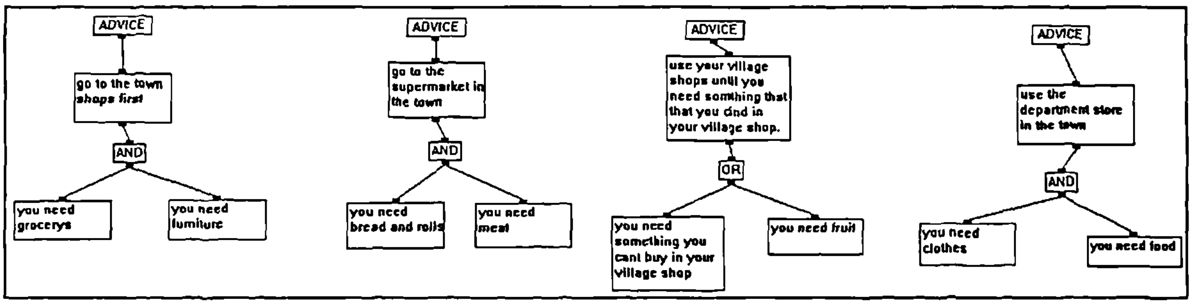

Figure 8.39 Vivian's attempt to create a more complex and sophisticated model

The other two groups, who created successful models unaided, built models with two levels of advice. Emily and Angela's model (Figure 8.40), does not produce appropriate questions for a visitor from another planet but the rules are properly constructed. They had concentrated on creating two levels of advice so that one followed from the other.

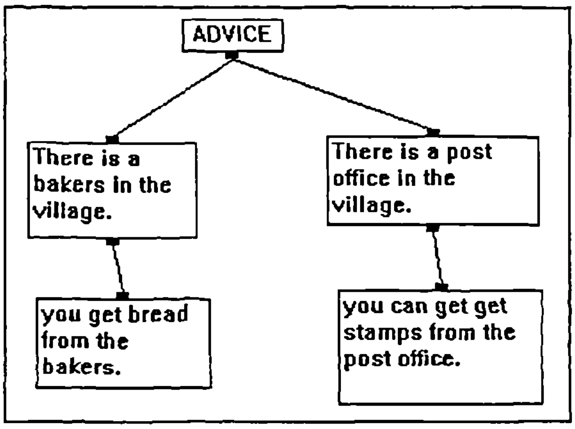

Figure 8.40 Emily and Angela's model with two levels of advice

Ian and Trevor's model (partly shown in Figure 8.41) made use of a rule structure that they had used for the "rocks" model. The problem was quite different from that of identifying rock types and yet they had found a very appropriate way of fitting a structure that they had used previously to a new task.

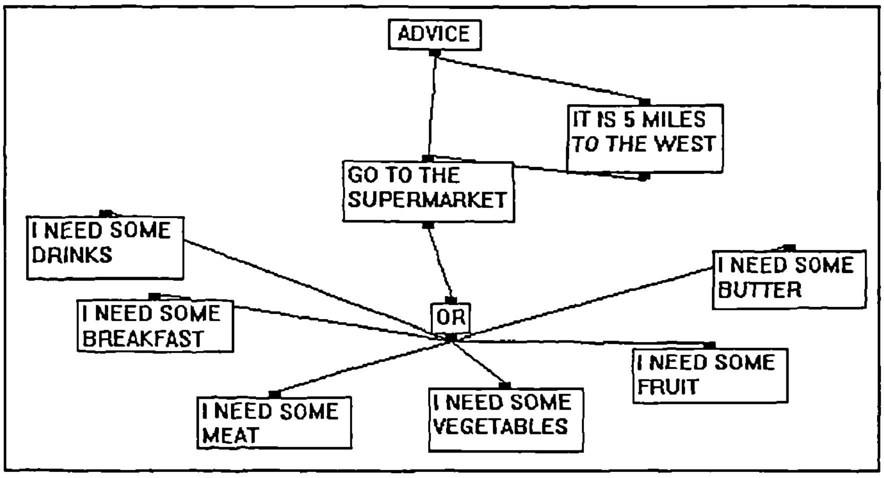

Figure 8.41 Ian and Trevor's model which used the same rule structure as the "rocks" model

8.3.3.5 What mistakes were made?

The other 13 groups made a variety of mistakes in the ways that they attempted to make use of the modelling metaphor. Table 8.8 summarises the mistakes they made.

Table 8.8 Mistakes which pupils made when making use of the metaphor

Mistake	Number of groups
Creating advice statements only (with no conditions)	7
Attempting to create a sequence by threading boxes together	1
Confusion between logical operators	1
Confused model of the structure of the diagram	2
Structure upside down	1
Unsuitable statements in premises which will become questions	1
Writing questions in boxes	2
Using logical operators between conclusions	3

8.3.3.6 Creating advice statements only

This approach represented a limited use of the modelling metaphor. Pupils were aware that the system could give pieces of advice but made no attempt to include conditions. This is partly explained by the observation that pupils confused the two dialogue boxes, which presented questions and advice, when they were running their models. However, even some pupils who had previously shown that they were aware that the system asked questions and then presented advice, depending on the answers, ignored this feature of the system when they constructed models. They focused on the need to provide advice and were aware that the system could do this. The groups who made this mistake were generally confused about how to link their statements together and they created a range of structures. Those who included logical operators generally received error messages that did not help them to restructure their models. Others who used simple links were able to run their models.

In the example shown in Figure 8.42 the pupil thought that his model was working since all the statements were presented when he questioned the system even though some were questions and some advice. In this particular case the other member of the pair was Vivian, a girl of higher ability who had already attempted this exercise fairly successfully alone. She did not interfere while the above structure was being created but then went on to attempt to rearrange the model (see Figure 8.43).

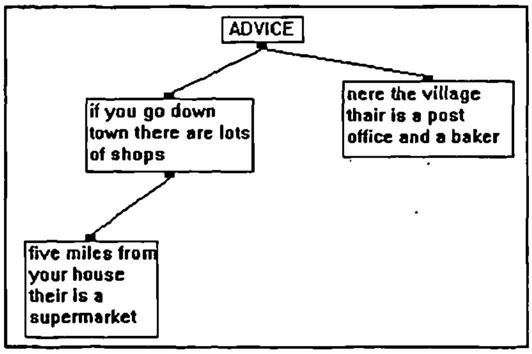

Figure 8.42 A model containing advice statements only built by a pupil in School A

Vivian was able to restructure the model quite rapidly into one that worked adequately. This facility to restructure a model quickly by moving boxes and altering connections was very important when one of the most time consuming aspects of the modelling process was typing. It also enables pupils to try out new ideas and test their effects quickly.

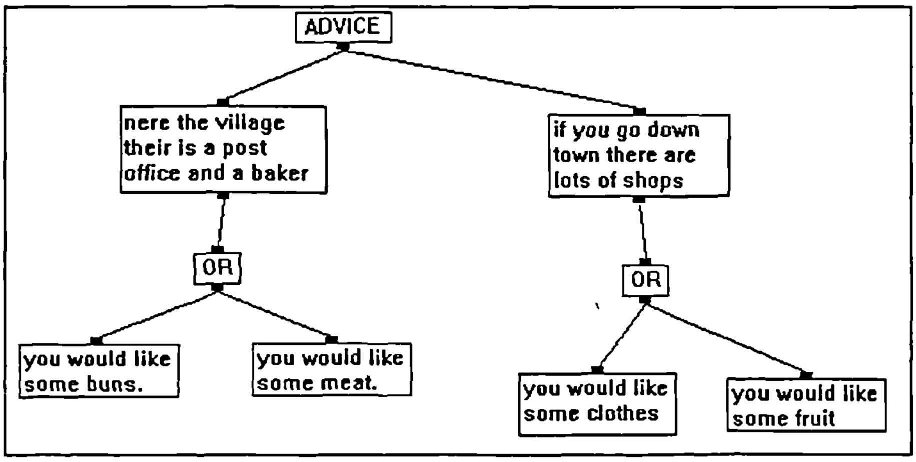

Figure 8.43 Vivian's attempt to rearrange the model that was shown in Figure 8.42

8.3.3.7 Attempting to create a sequence by threading boxes together

A decision that a model requires a sequence presents a problem when implementing the model in Expert Builder. The shell does not deal with temporal logic so while it is possible to build a simple sequence of conclusions, the conclusions are all tested depending on the conditions at a particular instant. There is no option to change answers previously supplied. The shell is therefore unsuitable for building event based simulations although it is possible to give a sequence of pieces of advice by placing them from left to right. The group who tried to create the sequential model had not discovered this feature and they attempted to make a sequence by threading the boxes together in such a way that their model would not run effectively. During the earlier work, they had been given no help on how to model a sequence in Expert Builder.

As mentioned earlier this was a feature that could detract from the declarative nature of the metaphor. Focusing on sequencing statements can distract the modeller from thinking about the conditions under which each statement applies. It is difficult to suggest how learners could move on from a sequential model to a rule-based one. A number of software packages, including Viewdata systems, already permit the construction of a sequence of frames describing events. Arranging processes in order could be a useful modelling exercise. It would be valuable to provide a computer based modelling environment that explicitly aids the task by providing a diagrammatic representation. Schools have made use of Viewdata systems for constructing branching stories and very often planned the story on a wall chart in order to outline the structure as a flow chart. When modelling with Expert Builder, this kind of sequential modelling should be discouraged and instead modellers should be directed towards an environment that was designed for the task. Several responses from members of the Modus Club suggested that the left to right search feature should be removed because it introduces a procedural feature into a declarative environment. It is a difficult dilemma because making use of the facility enables a further group of models to be constructed by the more experienced modeller but the feature adds extra complexity for the learner. One of the most difficult aspects of computer based modelling is the selection of an appropriate tool and for inexperienced users there is currently no substitute for teacher guidance. It would be advantageous to users if they could use one coherent software environment for a wide range of types of models. Therefore, rather than restricting the techniques that were available, it would be desirable to look at ways in which users could be helped to make use of the features in a sophisticated environment.

8.3.3.8 Confusion between logical operators

During this activity pupils had very little difficulty in selecting appropriate logical operators but they generally used simple rule structures rather than the more complex types that many had experienced difficulty in interpreting in Exercise 1. Only one instance noted was where a pupil used a NOT where an AND was required but she realised her mistake later and changed it before testing the model. They did, however, show some confusion about where it was appropriate to use logical connectors and this is discussed in Section 8.3.3.12.

8.3.3.9 Using a confused model of the structure of the diagram

Undoubtedly most of the pupils had a very incomplete mental model of the way a rule diagram could be structured. Some had an accurate view of at least part of the diagram and used this subset of the facilities in their model. However two groups laid out a fairly elaborate but inappropriate structure before inputting any text, suggesting that they were using a detailed but inaccurate model of the rule structure. The group whose model is shown in Figure 8.44 showed awareness of the need for clause boxes for premises and conclusions but used a complex and inappropriate structure. The class had previously worked on a model where a similar structure had proved appropriate so it is suggested that this group had remembered the diagrammatic layout used without understanding how it functioned.

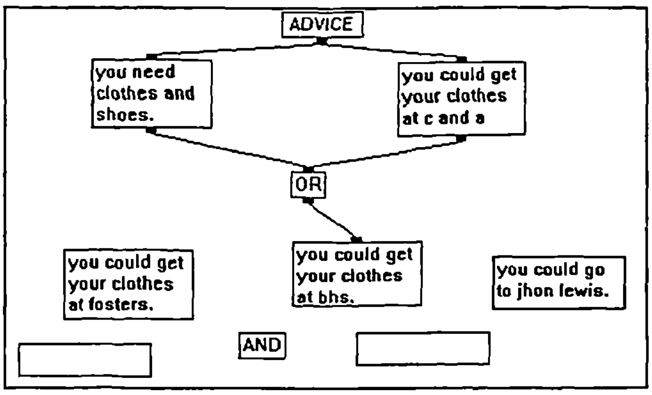

Figure 8.44 A model showing awareness of the need for clause boxes for premises and conclusions but using a complex and inappropriate structure

The other group who laid out a strange diagrammatic structure at the start (Figure 8.45) were from the same class and their structure was similar suggesting that it was based on one the class had used previously. They also failed to make use of both premises and conclusions, i.e. their statements all appear to be pieces of advice.

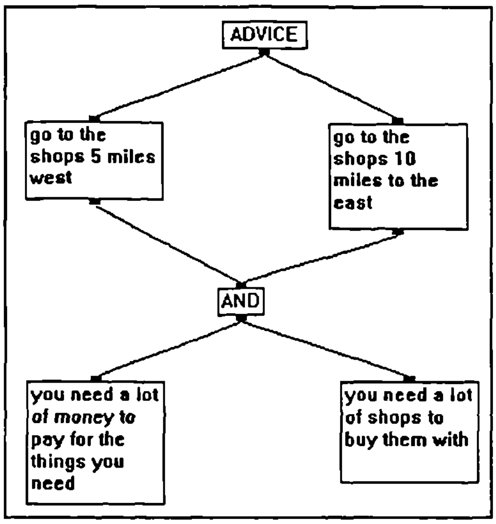

Figure 8.45 A model with a strange diagrammatic structure built by pupils in School A

These groups were from School A where the teacher had guided the pupils into creating models with complex diagrams such as the "holidays" model. It is likely that some pupils had remembered some aspects of the layout of the diagram without having any understanding of its meaning. Several of the pupils from School A, on the other hand, had not been confused by these complex diagrams. For example, Vivian, whose model was shown in Figure 8.39, was able to use the diagrammatic representation facilities to tackle the construction of the fairly complex modelling task that she set herself.

8.3.3.10 Structure upside down

This mistake was only made by one group at this stage. Their initial attempt is shown in Figure 8.46.

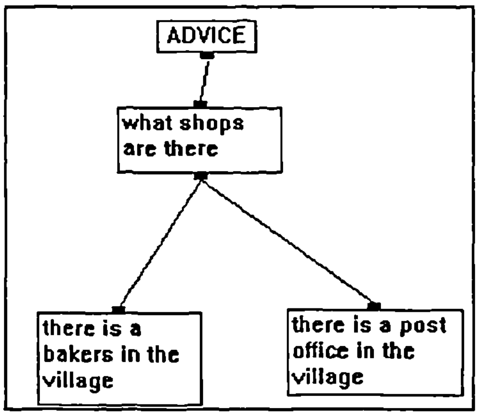

Figure 8.46 A model with an upside down structure

These pupils had very little idea of how to structure their model. They did start to think about what they wanted their model to do but their discussion suggests that their mental model of the system was extremely limited.

Emily	*Have you got to ask questions like the mouse one so a box comes up and you say yes or no or whatever?* (to the investigator)
Investigator	*Yes it will do that for you automatically if you join the boxes together right*
Emily	*Yes we need an advice box*
Christine	*Which one?* (pause)
Investigator	*Advice is the light bulb*
Christine	*Oh yes* (creates advice box) (pause) *Which shops she should go to and what stuff you get from shops. What shops? er*
Emily	*What shops should I go to?*
Christine	*Um the baker's* (typing - is there a baker's) *We could do what shops there are and what they - sort of sell.*
Emily	*Yeah and then we could do (pause).*
Christine	*Yeah I'll put there is so and so shops. There is a* (typing) *What shops are there? Are we doing the town?*
Emily	*No You could put a bakers and a post office and a butchers. Put bakers.*
Christine	(Typing)
Emily	*There is a --. Join them together. (Christine joins to advice). Then you could join them up and put. You could put there is a bakers and a post office.*

For these pupils the problem solving exercise of working out what they wanted their model to do was probably sufficient challenge at this stage without the need to make use of a modelling metaphor other than an extremely simple one. They went on to test their model and realised that it didn't function in the way that they had hoped. Their attempts to improve it were obviously based on trial and error and resulted in further problems. However, when they had been given some help in restructuring their model they were able to go on and add to it.

8.3.3.11 Writing questions in boxes

Throughout the study it was noted, on a number of occasions that pupils wrote questions in boxes rather than leaving the system to turn statements into questions. For example, the clause "you need clothes" will be presented by the system as "Is it true that you need clothes". During this exercise only two groups made this mistake. It is not very important since it does not affect the logical structure of the model but it does suggest, as mentioned previously, that they are not reading the dialogue box carefully.

8.3.3.12 Using logical operators between conclusions

The Expert Builder rule structure was:

conclusion if premise

where the premise could contain several clauses joined by logical operators but the conclusion needed to be a single statement. Of the 3 groups who attempted to join conclusions with logical operators, two created structures that were very muddled but one group was clearly trying to represent several pieces of advice that could be given to the user by linking them with OR. These groups tried to use the logical operator, OR, as though it were the same as in normal speech therefore creating structures like that shown in Figure 8.47.

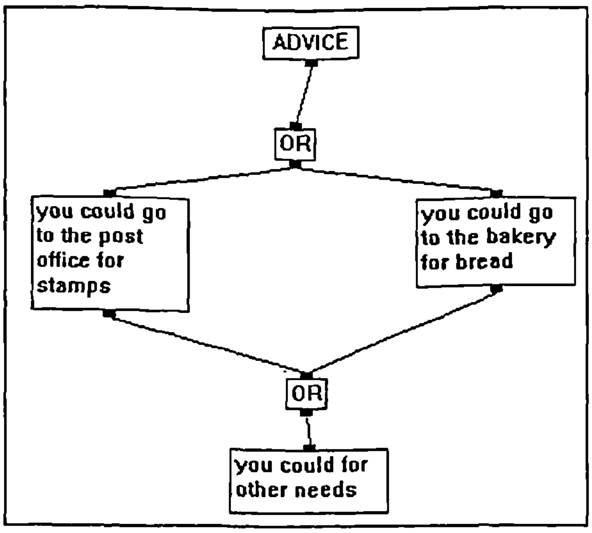

Figure 8.47 The use of OR between conclusions

8.3.3.13 Failing to be critical of their model

All groups except one attempted to make changes to their model when they tested it and observed problems. Therefore to some extent they were critically evaluating and improving their model. However most groups were pleased when they achieved a model that worked even if it did not do what they had set out to make it do. This stage of model building is very important but for all modellers there must be a point when they are satisfied with their model even though it is obviously not perfect. It was noticeable that those who were more confident in making use of the system metaphor were prepared to be more critical of their models and to try to achieve the functionality in their model that they had intended.

8.3.3.14 Summary of results of the test of competency

These results confirmed previous conclusions, described in Chapter 6, that the interface was generally easy to use at the mechanical level of selecting and operating the tools. Pupils' abilities to use the modelling metaphor appropriately to create models showed greater variation.

18% of the pupils tested had already developed an adequate mental model that enabled them to predict how a simple rule would be interpreted. A contributory factor to the confusion of the other 82% appeared to be the design of the dialogue box in which the questions and advice were presented.

73% were actually capable of following the reasoning mechanism by observing the on-screen trace and then making use of this to build a new rule. Those who were unable to create a new rule with a very similar structure to the one that they had been shown did not appear to see the similarity with what they had just been doing. The ability to recognise such similarity is an important modelling skill and the recognition of the need to look for such similarity is also important.

64% of the pupils could interpret simple rule diagrams containing the logical operator AND. However, in line with the findings of Henle (1962), discussed in Chapter 3, Section 3.5.2.1, pupils tended to interpret the model by using their own reasoning even when this conflicted with that shown on the diagram.

Considerable variation in modelling abilities was demonstrated by groups in the third exercise. Of the 17 groups who attempted Exercise 3, four succeeded, without help, in making appropriate use of the metaphor to create models that worked and had therefore adopted an adequate mental model of the modelling metaphor in relation to this particular problem. The other groups made various mistakes, which have been characterised here. None of the groups made any real attempt to plan their model but this was not unexpected since they had not been encouraged to do so during previous work.

8.4 Summary and conclusions from the classroom trials

Expert Builder was used by two teachers within their normal curriculum work covering the five different topics that they were working on during the year. In addition, during work, in School C where the investigator acted as tutor, pupils built models that extended and consolidated knowledge of the topic on which they were working. In School C the pupils were also given the opportunity to develop models on subjects of their own choice. They responded to this challenge with enthusiasm and were able to suggest appropriate tasks. Most of the pupils completed working models of varying degrees of complexity and with varying amounts of help. At the end of the study 22 of the pupils took a test of competence in using Expert Builder. This revealed important information about pupils' abilities in manipulating the interface, developing a mental model of the modelling metaphor, starting modelling, the nature of modelling tasks, teacher intervention, modelling and learning and cooperative working.

8.4.1 The range of models

Models were constructed on widely varying subjects and the model structures were quite varied. A majority of the models were classified as advice models, using the groupings discussed in Chapter 2, but there were also some classification and diagnostic models. The system encouraged advisory models by always designating conclusions provided to the user as advice. The models were also categorised according to the number of conclusions, the complexity of the conditions and the order of conclusions. Models with only one possible outcome or with a small number of clearly identifiable possible outcomes were successfully constructed, as introductory modelling exercises, by pupils with little help. Several models with a large number of possible outcomes were also constructed by pupils. Where the pupils tackled these models by building each rule and testing it they were successful but this method did not encourage a holistic approach to the problem as had been recommended in Chapter 2. It would still be possible to use a systems approach if some prior planning were done, perhaps on paper.

The number of models was obviously limited by the small size of the study but the variety of models created did suggest that both teachers and children had little difficulty in finding opportunities for using qualitative modelling.

8.4.2 Manipulating the interface

In both the initial study and the main study, pupils learnt to manipulate the tools rapidly and the interface presented no barrier to their progress. Improvements, after the initial study, made to the way the scissors and bobbin tools worked, meant that fewer problems were experienced with these tools in the main study. However the use of the scissors still caused some problems so this was a feature for future improvement.

It had been hoped to provide as much support as possible for knowledge elicitation, i.e. enabling modellers to express unclear ideas and then restructure the model as their ideas became clearer or they researched more information. However, in this study, modellers who set about creating boxes without a clear idea of the basic structure of their model ran into difficulties and had to be given help in restructuring. One of the reasons for this was the limited facilities for restructuring. Individual boxes could be moved easily but there was no facility for moving sections of the model. On the computers used in the classroom study, scrolling the model was also rather slow.

Solutions to the problems in manipulating the user interface are discussed in Chapter 10 (Section 10.8.2)

8.4.3 Developing a mental model of the modelling metaphor

A minority of pupils were able to structure and develop models without help towards the end of the study. They were therefore using adequate mental models of at least some aspects of the modelling metaphor. Most used rule structures that they had been shown but some experimented and found other structures. Most of the pupils who were successful did therefore search their minds for structures they had used previously. In some cases pupils attempted to use structures that they had been shown although their efforts showed that they did not understand how they worked. In some instances the teacher had shown them more complex structures which they had not been able to assimilate at that stage. Some, who were unsuccessful, did not even manage to identify and use a structure when it was still on the screen in front of them.

The pupils who were more successful in creating a model during Exercise 3 of the test were those who, during previous work, had worked on their own models and were shown simple techniques at the start. They experimented with new techniques themselves and were introduced to other features of the system when they requested help. All the pupils had some opportunity to work in this way but some had lacked the confidence to try their own ideas and had relied on other pupils or the teacher to help them.

8.4.4 Starting modelling

It was important that the first modelling exercise could be carried out successfully with a very simple rule structure. Showing pupils a model that had already been built probably gave them some feel for what the system could do but showing them how to build a few simple rules was more important. Making use of a more complex rule structure at an early stage, as in School A, probably led to two of the groups in Exercise 3 embarking on an over complex diagram, where they were attempting to copy a structure that they had been shown previously and hadn't grasped. The

Technology National Curriculum (Department of Education and Science and the Welsh Office 1990) stated that pupils should progress from using models and simulations and understanding their rules to building their own models but this study suggested that examining more complex model structures could hinder pupils success in model building. Pupils would develop modelling skills most effectively by undertaking a series of progressively more complex model building tasks.

8.4.5 The nature of modelling tasks

The study suggested that the selection of the modelling problem was very important. As discussed in Section 8.2.1, it is suggested that developing a complex model structure as the first exercise in School A hindered the development of the pupils' mental models of the modelling environment. Tasks were more successful where the teacher directed the pupils towards simple effective rule structures as in School B. Another important factor was pupils' degree of familiarity with the subject matter which altered the overall level of difficulty of the task. Pupils who chose to build models in areas with which they were familiar tended to be successful. This is consistent with findings of Carey (1985) and Keil (1986) who showed the importance of context in learning. The importance of context was also shown by the test of competency where it was found that pupils focused on the subject matter and applied their own reasoning rather than interpreting the logical structure of the model (see Section 8.3).

Prior experience with computers affected pupils' perceptions of the degree of difficulty of the task. Pupils who had used computers successfully for other tasks were more persistent and prepared to experiment.

8.4.6 Teacher intervention

In Section 8.2.7 it was suggested that the degree and type of teacher intervention differed according to whether the intervention was concerned with manipulating the software, structuring the model or selecting and structuring knowledge. Intervention concerned with manipulating the software generally involved immediate correction or instruction. Both teachers in Schools A and B were slightly more tentative in their intervention concerning inappropriate structuring of the model. The two teachers differed in the type of intervention in situations concerned with selecting and structuring knowledge. The teacher in School A asked fairly directed questions. When the teacher in School B noticed a problem in the knowledge content or the arrangement of the knowledge, he made more tentative suggestions about what the pupils might consider. The fact that the particular problem on which the pupils were focusing was clearly visible on the screen enabled the teacher to assess the situation quickly and to intervene with advice or instruction. Teacher intervention was important for helping the pupils to make appropriate use of the environment and for encouraging them to think carefully about how they selected and structured their knowledge.

8.4.7 Modelling and learning

The teachers viewed the modelling activities as opportunities for pupils to consolidate and extend their knowledge of the topics that they were working on. They encouraged the pupils to do this by the comments, reminders and suggestions that they gave when they intervened in the groups' work. In all three schools pupils were observed searching for information in books to incorporate into their models so the modelling activity was providing a focus and stimulus for their research. The need to select and structure the knowledge into the model focused pupils' attention on relevant knowledge.

Evidence of strong motivation included the prolonged periods of time during which pupils persisted in building their models, the willingness of some pupils to continue during lunch-times and the decisions of a number of pupils to work on their models rather than play games. It is suggested that increases in pupils' level of motivation, brought about by undertaking modelling activities, promoted pupils' learning and understanding of knowledge.

The modelling tasks involved active learning situations that required pupils to research and select information and to re-examine their own knowledge. They were therefore consistent with the constructivist approach to teaching and learning discussed in Chapter 3, Section 3.1.

There was evidence of long periods of concentrated effort but, except for Keith and Dean, who became very familiar with the software facilities that they needed for their model, a significant amount of the effort was directed towards structuring the model and using the software. This effort may have helped pupils to develop thinking skills and other skills needed for modelling but it may have actually detracted from learning of the subject matter by occupying time that might otherwise have been spent on developing knowledge and understanding of the subject matter.

The time needed to carry through a modelling task was an important factor in this study. Pupils were only able to focus on the modelling task when they had developed a mental model of the modelling environment that enabled them to envisage how they might represent their knowledge in order to achieve their desired outcome. In this study most of the groups had no more than four hours working on their models, even Dean and Keith only spent approximately seven hours on modelling. There was evidence that some pupils, mainly those with more experience and confidence in using computers, could start to build simple models, using knowledge with which they were familiar, after a fairly brief demonstration and some tutorial help. There was no doubt that learning to use the software occupied a high proportion of the time during the first two hours of use and some pupils needed longer than this to develop a simple mental model of the modelling environment.

In School A the teacher structured the tasks so that the pupils were making use of their knowledge of the subject matter and hence presumably consolidating it even though they had only limited experience of manipulating the software. In some of the activities in School A, particularly the "Holidays" and "Connections" activities, the teacher had designed the model structure and started the model construction and the pupils participated in building parts of the model. This approach was reminiscent of legitimate peripheral participation discussed in Chapter 3, Section 3.8.3. It enabled the teacher to encourage the children to concentrate on the subject matter of the model while gradually developing modelling skills. All the children were able to take some part in the modelling activity. The teacher encouraged them to research information, to formulate ideas and to develop their thinking further by his intervention. This approach is consistent with Vygotsky's idea of learning being in advance of development which is discussed in Chapter 3, Section 3.5.2.

In School B, where the children had more control over the modelling activity and the teacher's interventions were less directed, the children were always major participants in the modelling activity. They had to master minimum skills in using the software before they could make progress in the modelling activity and hence develop their understanding of the subject matter. The teacher devised the tasks so that they were achievable by the pupils with some help. The nature of the tasks and the intervention by the teacher encouraged learning that was slightly in advance of development. The only exception to this was the pair of girls, mentioned in Section 8.1.2.2, who were assessed by the teacher as being well below average in intellectual ability. These girls were only able to make progress with considerable help and so it was likely that the cognitive abilities required by the activity were outside their zones of proximal development.

Galpin (1989), conducted a project in English primary schools with children aged 8-11 using simple expert system shells, which is discussed in Chapter 3, Section 3.9.5. He reported that the teachers believed that some children appeared to benefit more than others from building expert systems. The teachers suggested that this was related to the child's stage of cognitive development. This notion of Piagetian stages of development is not accepted in this thesis. With the possible exception of the two girls in School B who were assessed as being well below average in intellectual ability, all pupils appeared to be learning about the subject matter and about modelling while they participated in the modelling activities. The pupils benefited from the activities because they were structured in such a way that it was possible for them to participate either as major participants or as peripheral participants.

The teachers designed the tasks with the abilities of their pupils in mind and provided support where necessary. The flexibility of the software enabled a range of different tasks to be devised. Some individuals showed particular interest and motivation and voluntarily spent more time on building their models and hence gained more understanding of the subject matter and the modelling process.

The modelling tasks clearly involved thinking and it is suggested that they were developing a variety of cognitive skills that may or may not have been transferable to other domains. As discussed in Chapter 3, Section 3.3, there was increasing evidence that such skills are context specific (Carey (1985), Keil (1986)). Children show certain cognitive abilities during one task but are unable to use such abilities to perform a different task. Therefore an educational activity should not be justified purely on the grounds that it develops general cognitive skills such as problem-solving skills. In these modelling activities the pupils were employing a range of cognitive skills while developing their understanding of a range of specific topics. The tasks had been designed by the teachers in order to develop children's knowledge and understanding of particular topics. The modelling tasks provided opportunities for developing thinking and problem-solving skills and for practising these skills. Even though these skills do not always transfer from one task to another, it is only by developing these skills in a range of situations that they gradually become generaliseable. The skills and abilities involved in computer based modelling are explored in more detail in Chapter 9.

8.4.8 Cooperative working

During this study pupils worked in groups of two or three and in most groups, one member manipulated the mouse and another used the keyboard. If there was a third member, (s)he either made comments and suggestions, or made little contribution, while (s)he was not manipulating the mouse or keyboard. This depended on her/his personality as well as other factors that could not be fully identified in this study. The pupils swapped round at intervals so the member with no specific role was not always the same person. Most groups organised this themselves and generally they cooperated well about taking turns. The use of Expert Builder encouraged cooperative working of pairs of pupils because the most efficient method of working was for one member to operate the mouse and the other the keyboard and all groups worked in this way without being instructed. Each therefore had to consider the other's intentions. Both participants could be involved in building the model since one of the members was positioning and linking boxes and the other was typing the text. Pupils generally cooperated well within the pairs and most of the groups of three also cooperated well.

During the later stages of the modelling activities the talk showed that the pupils were working together to structure the model and to use the software. The screen view of the model helped the pupils to communicate their intentions by pointing at the structures on the diagram. This finding is consistent with Noreen Webb's conclusion (Webb, 1984) who suggested that when using a computer the strategies or approaches and results can be seen clearly by everyone because they appear on the screen in a standardised fashion. Therefore pupils can learn from what other group members *do* as well as from what they *say*. The nature of the talk suggested that pupils were learning how to use the software environment and how to structure the model by interacting with each other.

8.4.9 General summary

In this study pupils have successfully undertaken qualitative modelling tasks that arose from their normal classroom work. The models that were constructed have been classified and the pupil interactions and teacher intervention have been characterised and discussed. The extent and nature of pupils' mental models of the modelling metaphor have been examined and the development of these mental models has been discussed. Strengths and weaknesses of qualitative modelling in general and of Expert Builder in particular have been identified. The nature of the modelling tasks as learning activities has been discussed and it was concluded that they involved active learning, the development of knowledge and understanding and the development of a range of cognitive skills. In Chapter 9 a detailed analysis of the modelling process is discussed and one of the modelling activities is analysed in order to try to characterise the modelling skills and to move towards a taxonomy of modelling skills.

Chapter 9 A Taxonomy of Computer Based Modelling

In this chapter a new taxonomy of computer based modelling is proposed. This was developed by examining some of the modelling activities that were discussed in Chapter 8, in terms of three existing taxonomies, to assess their adequacy.

The requirements for computer based modelling specified in the National Curriculum for England and Wales are considered with reference to the modelling process, the taxonomy of computer based modelling and the development of modelling skills.

9.1 Applying the modelling process in the classroom

In Chapter 2 (Section 2.1) the modelling process was described as a structured process very similar to the systems analysis process. A diagram of the modelling process as it might be undertaken by any modeller, including a learner who was making use of the modelling process, was presented and is reproduced in Figure 9.1. Some of the modelling activities that were described in Chapter 8 will be re-examined here in terms of this modelling process so that skills involved in modelling can be identified.

In the classroom evaluation the scenario was different from one in which modelling is done in 'real world' situations, since the purpose of this research was to investigate modelling in an educational setting. The teachers were presented with the software and asked to identify opportunities for its use during their normal classroom work. Therefore, whereas in a 'real world' situation, as described in Chapter 2, modelling would be used as a need arose, in these circumstances the teachers were looking for problems or situations to model. Another difference was that the modelling environment was specified, therefore there was no opportunity to select a modelling environment that might be particularly suited to the problem. The teachers effectively did a pre-run through the modelling process in order to ensure that the problem could be tackled through modelling and that the software environment was appropriate. In the pilot study and in the main study in the three primary schools, the teachers' objectives were concerned with understanding of the subject matter and developing problem solving skills rather than developing an understanding of the modelling process, nevertheless opportunities were provided for pupils to be aware of various aspects of the modelling process.

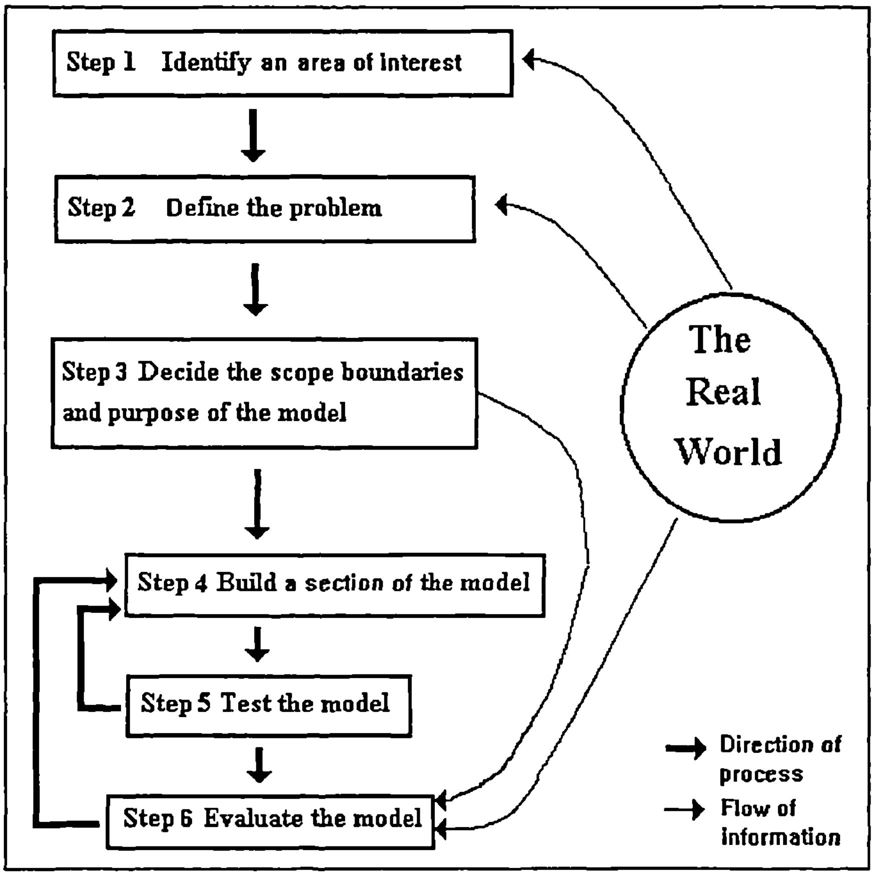

Figure 9.1 The framework for the modelling process

In the activities in Schools A and B and in the majority of activities reported from other schools the work started with either a class discussion or some research where the pupils were building up knowledge and understanding of the problem and its context. The only exceptions to this were reports of project work undertaken by pupils aged 15 to 19 years and in School C where pupils were enabled to construct models on topics of their own choice. In Schools A and B and in most other activities reported, teachers identified the problem to be modelled and explained the problem and the purpose of the model to the pupils. The teachers were therefore carrying out steps 1 to 3 of the modelling process (see Figure 9.1). It was notable that at step 3 the purpose of the model was usually well specified although the scope and boundaries of the model were left more vague. It was actually quite difficult to build a model in Expert Builder without a clearly defined purpose because a model needed conclusions that could be questioned. One instance, observed in a secondary school, where a teacher did not make clear the purpose of the model, resulted in pupils linking together factors that were related without considering what the conclusions in the model were (see Figure 9.2).

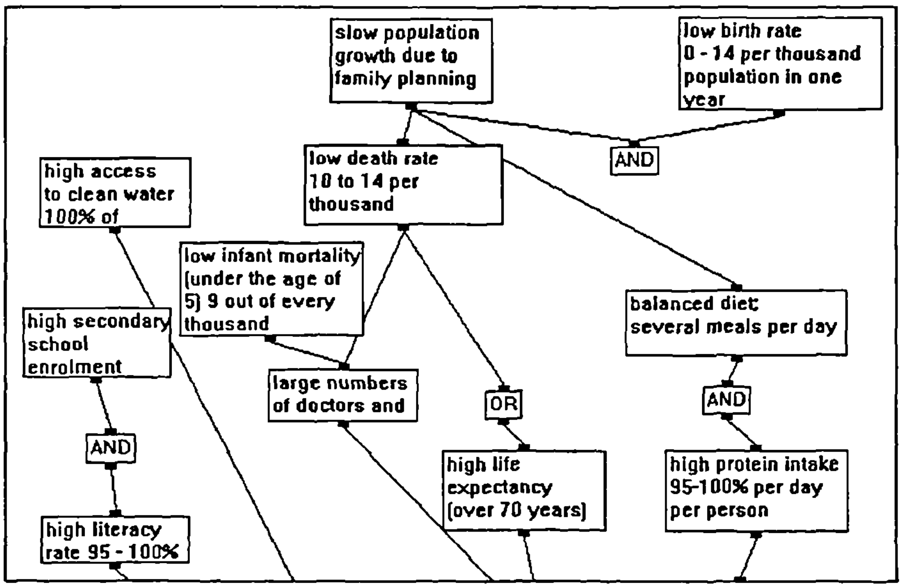

Figure 9.2 A model where pupils have linked factors without being clear about the conclusions

There were obviously other problems with this diagram. The pupils did not understand the basic rule structure. A more fundamental problem is that they were not clear about the purpose of the model so the model is a network of ideas rather than being focused on solving a problem. Later the pupils were given some further instruction in how the rule structure was created. In addition, the teacher focused attention on the purpose of the model which was to classify a country as developed or developing. Students were then able to rearrange the factors so that the user of the model could give answers for a particular country. The model would then infer whether the country could be classified as developed.

During the classroom work in School A much of the modelling process was carried out by the teacher. He carried out steps 1 to 3 of the process involving the pupils to some extent by class discussions. Step 4 was also a class exercise particularly in the first two activities - "where to go on holiday" and "selecting a hotel". The teacher decided the structure of the model and the pupils were directed to build parts of it to a fairly well specified blue-print. In the third exercise concerned with conserving energy the pupils did tackle most of step 4 with little help and they also tested the model carefully. A certain amount of evaluation was done. The pupils tested the model to ensure that it behaved as they intended but there was no attempt to assess the fitness of the model for its purpose or to specify limitations in the model.

In School B the teacher decided the problem and the scope and purpose of the model but the pupils were encouraged to investigate ways of structuring the model following only a brief demonstration of Expert Builder. They were then given some help when they needed it but to a large extent pupils tackled steps 4 and 5 of the modelling process themselves and to some extent step 6.

In School C the original instructional plan had been for pupils to construct their own simple models on selecting clothes following a brief demonstration of Expert Builder. This would familiarise them with the software and enable them to construct models on the topic that they were currently studying. This plan was revised when pupils requested to be able to build models on subjects of their own choosing. This modelling activity, although brief, was quite successful. Students identified areas that they were interested in which they felt could be modelled qualitatively having seen one example of how a model could be constructed (see Section 8.1.1.1). They discussed the definition of the problem and the purpose of the model with the investigator and they then went on to build and test their model in stages. They therefore tackled steps 1 to 5 of the modelling process (see Figure 9.1).

As mentioned earlier, in Schools A and B steps 1 and 2 of the modelling process were carried out mainly by the teachers. One reason for this was that they regarded the modelling activities as opportunities for pupils to extend and consolidate their knowledge and understanding and so they needed to exercise control over the subject matter so that they could provide opportunities for pupils to learn appropriate material.

However they also said that they felt that these early stages in the modelling process were particularly difficult, requiring a diverse range of complex cognitive skills. The experience in School C suggested that pupils could undertake steps 1 and 2 in areas in which they were already interested and knowledgeable. At this stage they needed help both with using the tools and with dealing with the logic and the modelling metaphor so whenever they requested help or appeared to be unsure they were shown how to achieve their objectives or given suggestions. Later when they were given a subsequent opportunity to choose a modelling problem some pupils were able to undertake the whole modelling task with very limited help. Those groups who were successful in their chosen tasks, during the first stage of this work, were more successful in structuring their "rock identification" models. In this activity a basic structure for the model was taught but some groups, on testing their models, decided that they required slightly different functioning and experimented with the structure to try to achieve this with some success.

Reports on other modelling experiences were sent into the Modus project and showed that students aged 16 to 19 had undertaken project work in which they carried out most of the modelling process. However in all cases there was a somewhat contrived situation in which pupils were presented with the software, shown its features, and asked to identify a problem that could be tackled using this environment.

In summary the modelling activities in the detailed classroom studies generally started with either a class discussion or some research where the pupils were building up knowledge and understanding of the problem and its context. The teachers usually identified the problem to be modelled and explained the problem and the purpose of the model to the pupils. The teachers were therefore carrying out steps 1 to 3 of the modelling process. The experience in School C suggested that pupils could undertake the whole modelling process in areas in which they were already interested and knowledgeable. In this situation the pupils had more ownership of the problem and they showed a high level of motivation.

9.2 Defining modelling skills and processes

The framework for the modelling process made it possible to assess to what extent pupils were performing all the stages of modelling during the classroom activities. A further need was to identify the skills and abilities required for modelling and thereby to clarify the intellectual requirements for undertaking the different steps in the modelling process. Once these were identified, it might then be possible to determine which of these skills and processes were evident in the examples of children modelling in this study. The aim of identifying the skills and processes displayed by children in a number of instances was to illustrate the learning opportunities offered through modelling activities and also to give guidelines to enable people to become successful modellers.

Clearly, when the model is actually being constructed and tested on the computer a number of practical and manipulative skills are involved. But throughout the earlier stages as well as at the construction stage, a variety of cognitive and metacognitive skills are in use as well as communications skills. An analysis of these skills and abilities could enable the development of a taxonomy of computer based modelling. Such a system of classifying computer based modelling activities could enable them to be analysed and compared for their component skills. This could be of practical use to teachers when planning activities because it would enable them to design activities that would provide opportunities to develop particular skills or processes. Three possible taxonomic approaches were identified and discussed in Chapter 3 (Section 3.10): Kyllonen and Shute's (1989) taxonomy of learning skills, Ennis's (1987) taxonomy of critical thinking dispositions and abilities and Sternberg's (1985) componential subtheory.

9.3 Kyllonen and Shute's taxonomy of learning

Kyllonen and Shute's taxonomy was applied to the data from one of the classroom modelling activities described in Chapter 8 (Section 8.1.2.2). The activity chosen was the development of a model to identify bones, carried out in School B by two nine-year old boys, Dean and Keith. This activity was chosen for analysis because it was felt by the teacher and myself to be a successful attempt at modelling which had been followed through to a reasonably complete model. In addition a fairly detailed record had been made of most of the activity. The analysis was applied to the complete record of the activity that involved interaction between the students, the students and the computer and the students and the teacher. This analysis is only intended to give a rough indication of the time spent exercising various skills. A more rigorous analysis could produce a precise breakdown of the time spent exercising and testing various learning skills.

Kyllonen and Shute selected four dimensions as particularly important in classifying learning skills:

- instructional environment
- knowledge type
- domain
- learning style

Kyllonen and Shute suggested that in applying their taxonomy the researcher should initially categorise the instructional programs in their domain space and then make use of a matrix of instructional environment and knowledge type (see Figures 9.4 and 9.5). They should then consider the learning style issue by examining whether particular learning styles were encouraged. The main technique then in applying this taxonomy was to score the matrix of instructional environment and knowledge type.

Kyllonen and Shute produced two scores, one for the time spent engaging the learning skill and the other on testing for the learning skill. There was no formal testing built into the "Bones" modelling activity; instead the students exercised their skills through building the model so that their actions and talk gave evidence of their learning but it was only possible to give one score, i.e. that for the time spent engaging the learning skill.

In the classroom modelling activity the explicit and implicit learning goals were quite varied and included:

- extending and consolidating knowledge of the names, characteristics, arrangement and function of bones and skeletons
- developing modelling skills
- developing skills in using this particular software
- developing more general computer skills
- developing problem solving ability through tackling an unfamiliar task
- developing information retrieval skills involving extracting relevant information from written material
- developing ability to interpret diagrammatic representations and to relate them to concrete structures
- developing cooperative learning skills - for this exercise the teacher had deliberately paired these two boys together because they worked well together.

One of the boys was underachieving, according to his teacher, because he made little effort in conventional learning situations.

The learning environment used in this modelling exercise was more varied and complex than the instructional programs to which Kyllonen and Shute applied their taxonomy. The initial instructional environment was didactic but the teacher gradually gave control to the pupils so that they were learning to manipulate the modelling environment by practice. The pupils structured their model by mapping from parts of the model already built to new structures. This was categorised as learning by analogy rather than from examples because the process was predominantly mapping from one knowledge structure to another similar one and there was no requirement to attempt a generalisation. The pupils were also able to discover rules about using the environment such as the rule that advice statements needed to be linked to an advice box but it didn't matter how many advice boxes were used. The teacher provided help when requested and sometimes intervened to provide instruction on a particular point. Several stages in the construction of the model are described and illustrated in Chapter 8 (Section 8.1.2.2) and Figure 9.3 shows the typical structure of the rule diagram.

During the second session the pair continued to build the model, learning by practising what they had learnt from the previous session when they had been given instruction, by analogy and by observation and discovery. In a subsequent session the investigator worked with them, instructing them how to improve their model and overcome some of the problems they had encountered. This involved some didactic instruction followed by practice in applying rules and pupils asked questions so learnt from examples. They then spent a further two sessions, working predominantly on their own, using practice, analogy and discovery.

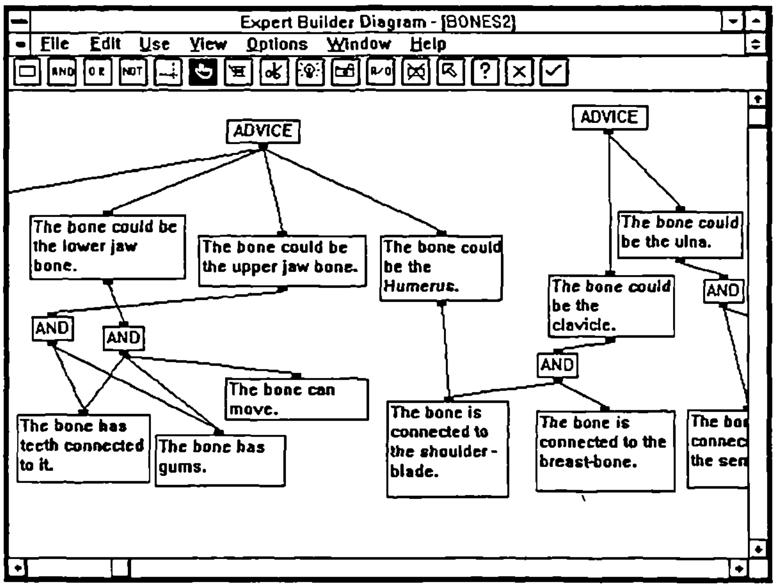

Figure 9.3 Part of the "Bones" model

The employment of declarative knowledge of the subject matter was identified since the pupils built this into their model. The knowledge was about the structural arrangement of bones and their functions and so consisted of propositions about the names and positions of bones and schema concerning how to identify a particular bone with precision and the knowledge about the functions of bones.

Procedural knowledge included manipulating the modelling environment and structuring the model as well as some knowledge about the methods that could be used for identifying bones. In addition there was procedural knowledge about obtaining information from the secondary sources. There were specific rules about how and when to use each tool and when a number of these were employed to construct a section of diagram this would become a skill. Since this exercise involved building only one model in one subject area the rules and skills were only demonstrated in this specific context but pupils might have learnt their generality across a range of models and across other problem solving tasks. This was tested later, by the "test of competency" which is discussed in Chapter 8 (Section 8.3), but for this exercise the skills and rules were considered to be specific hence there are no general rules or skills recorded in figure 9.4. Kyllonen and Shute defined an automatic skill as one in which two types of behaviour are being performed simultaneously. A pupil constructing a section of diagram while discussing the content of the model would be an example of an application of an automatic skill but this phenomenon was not observed during this activity.

The "test of competency" that these pupils completed following this exercise, showed that they had developed mental models of the modelling metaphor that enabled them to construct similar models. The mental models' school of thought, which is discussed in Chapter 3 (Section 3.4.1), proposed that people construct mental models of everything with which they interact. While they were working with a modelling environment, users would construct mental models of the situation they were modelling and also of the modelling environment itself. Scoring the amount of time spent on learning a mental model would be difficult because there would be no conscious attempt by the teacher or pupil to develop the mental model. The process of constructing or reconstructing a model might take place quite frequently since Johnson-Laird (1983) stated that mental models are often inaccurate and according to Norman (1983) mental models are incomplete and unstable. The mental model could develop gradually as the knowledge was assimilated. Evidence for the existence of pupils' mental models was only seen when they applied them to new situations so that during this activity, although pupils may have been developing mental models, it was not possible to score this in the analysis.

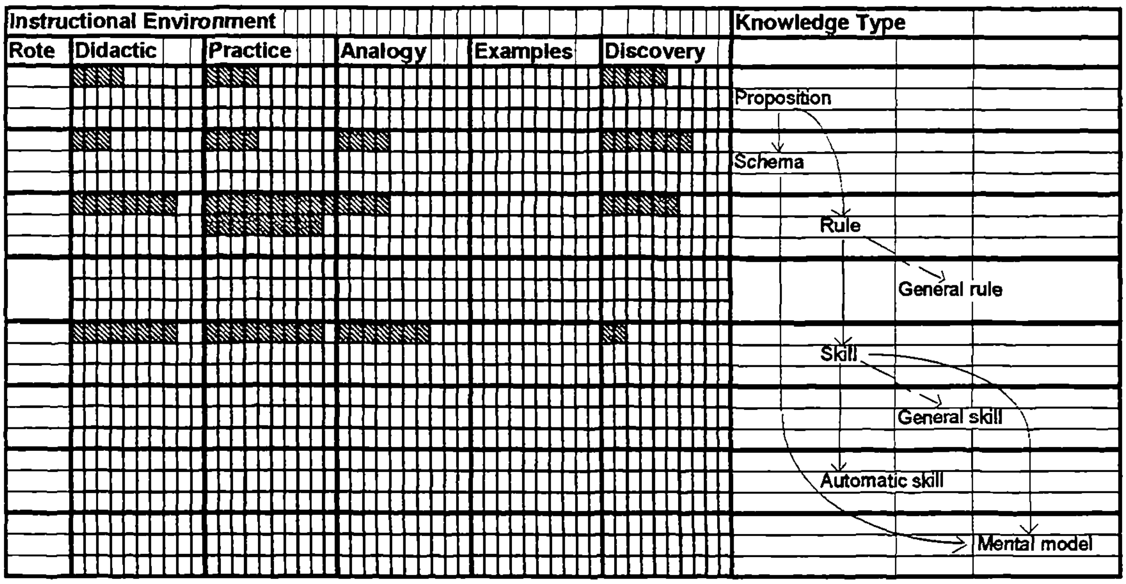

Figure 9.4 Learning activities profile for the "Bones" exercise (Each shaded small box represents approximately 5 minutes)

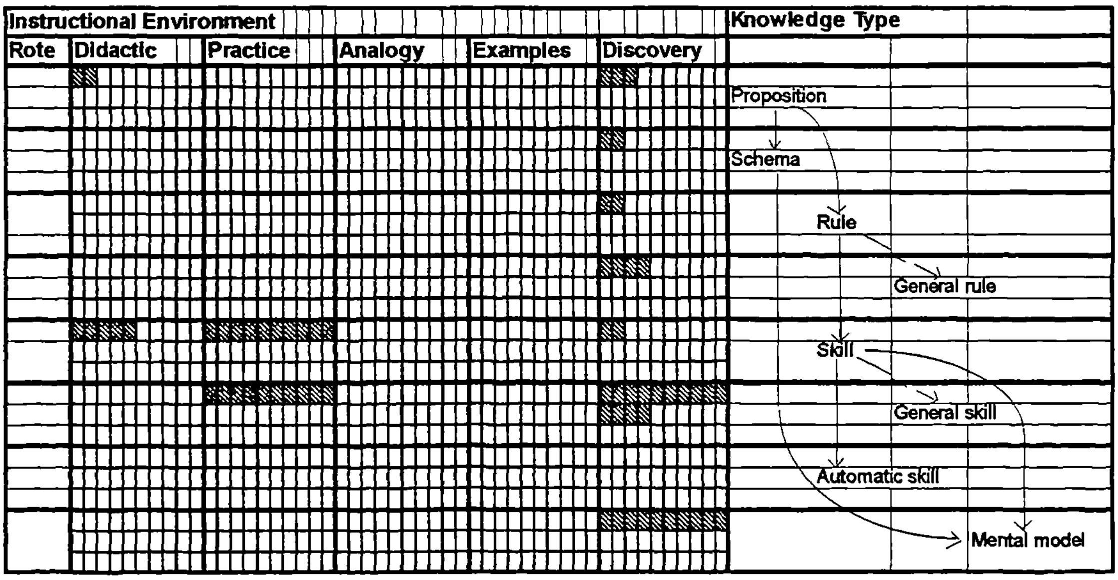

Figure 9.5 Learning activities profile for Smithtown (from Kyllonen and Shute).

Figure 9.4 shows an analysis of the skills that were being exercised in the activity using the same matrix as that used by Kyllonen and Shute. The diagram represents a knowledge type by instructional environment matrix. The arrows between the knowledge types represent a hierarchy of dependencies, e.g. a schema consists of a packet of related propositions. The skills have been roughly quantified based on notes made during observations and transcriptions of the tapes. One shaded small box represents approximately five minutes during which the skill, defined by the instructional environment by knowledge type grid, was used. For example about 20 minutes was spent learning propositions in a didactic instructional environment. Figure 9.5 shows the analysis of the skills that were being exercised in an activity, analysed by Kyllonen and Shute, where students were using Smithtown, a discovery world for economic principles.

The profile for the modelling exercise revealed that a fairly balanced mixes of types of instructional environment were used. Analogy was more important in this activity than for Smithtown. This probably reflected an important modelling technique in which structures that have worked previously were selected again to represent similar knowledge structures or processes.

The domain for the modelling exercise could be characterised as qualitative in that all the rules were purely descriptive, there being no quantitative factors involved. Nevertheless the subject matter might be described as quite technical requiring precise definitions rather than abstract descriptions.

Kyllonen and Shute identified learning style as an important factor but did not analyse it in their discussion. They decided that in the absence of a clear understanding of style variables their research on basic learning skills could be better performed on more structured environments such as BIP (BASIC INSTRUCTION PROGRAM) and the LISP tutor where the more directed learning activities designate a less important role for individual variability in learning style. In Smithtown they identified learning style as a particularly important factor although they did not characterise its dimensionality. Smithtown was highly interactive. The student would generate problems and hypotheses such as "Does increasing the price of coffee affect the supply or demand of tea?" and then the student would test these hypotheses by executing a series of actions, such as changing the values of two variables and obtaining a bivariate plot. The

Smithtown program collects and monitors a set of indicators, for example, indicators of exploratory behaviours include the number of independent variables changed and the number of times market sales information is viewed. These are really style indicators rather than direct indicators of learning skill in that they reveal how an individual organises her/his learning environment. Of the three learning systems analysed by Kyllonen and Shute, BIP, the LISP tutor and Smithtown, the latter was more similar to a modelling activity in that there was a high level of student control and opportunities for variation in learning style. Just as the designers of Smithtown identified learning style indicators as important in that discovery environment, style is likely to be an important factor in modelling.

Observation suggested that, of the aspects of learning style suggested by Kyllonen and Shute, the following were being encouraged in this modelling activity:

- a systematic approach in that the pupils were working step by step through the bones in the skeleton.
- spatial representation - the pupils were working with a diagrammatic representation of the logic in the decision-making process as well as with a three dimensional model and diagrams of the skeleton.
- deep processing - the pupils were involved in reorganising their knowledge into a new structure rather than recalling facts at a superficial level.
- active involvement - the pupils were actively engaged in building the model, finding information from books and examining the plastic skeleton.
- high internal motivation - the pupils followed the exercise through to completion which involved voluntary work at lunch-time.

Kyllonen and Shute's taxonomy of learning provides a learning task analysis system whose advantages are:

- It focuses attention on the instructional environments thus enabling consideration of whether these instructional environments were pertinent and whether the balance of instructional environments was appropriate. (In this example a fairly wide range of instructional environments was used and their use was spread quite evenly. This may not have been true for all the modelling activities.)

- It focuses attention on the knowledge types that are being learnt. (The resulting profile showed only broad types but during the analysis these could be considered in some detail and it would be possible to distinguish different types of rules and skills. This would be necessary in order to determine more precisely what was being learnt.)
- The linking of instructional environment to knowledge type enables determination of the means by which knowledge of different types is acquired. (In this example practice played a large role in the acquisition of rules.)
- It focuses attention on learning style although there was no clear indication of which variables are relevant.

Limitations of the taxonomy with regard to modelling activities were:

- The lack of a clear definition of which aspects of learning style may be important. (Kyllonen and Shute discussed this but they did not analyse it in their discussion of the three programs.)
- The lack of any consideration of the social context of learning which was discussed in Chapter 3 (Section 3.10).
- The limited attention to higher order thinking skills. (These would be considered to some extent in relation to learning style. However the reflective thinking towards a practical solution, which is demanded by the modelling process, suggested that more attention should be paid towards classifying these skills.)

The application of Kyllonen and Shute's taxonomy therefore provided a partial characterisation of the modelling activity in terms of the learning skills that were developed. It is a research tool that was relatively easy to apply and enabled some comparisons to be made between different activities. In the context of modelling activities it did not capture all the important aspects of the process. The decision of Kyllonen and Shute that their research using this taxonomy to clarify basic learning skills could be better performed on more structured learning environments, was consistent with the view that this taxonomy was not adequate for open-ended learning environments such as computer based modelling.

9. 4 Applying Ennis's critical thinking taxonomy

Ennis (1987) distinguished between critical thinking and the *higher order thinking skills* in part because he claimed that the latter concept was vague and also because critical thinking was essentially a practical activity. Critical thinking included most or all of the directly practical higher order thinking skills and also included "dispositions" thus reflecting the idea that critical thinking was essentially a practical activity and demanded active involvement. People could be "disposed to act" in a particular way. This did not mean that they would always act in accordance with these dispositions but their dispositions, which might be based on prior experience and social and emotional factors, would influence their behaviour in a particular situation.

The modelling activities, described in Chapter 8, were examined with reference to Ennis's critical thinking taxonomy. The most interesting aspect of Ennis's taxonomy in relation to modelling was found to be his set of fourteen dispositions:

1. Seek a clear statement of the thesis or question
2. Seek reasons
3. Try to be well informed
4. Use and mention credible sources
5. Take into account the total situation
6. Try to remain relevant to the main point
7. Keep in mind the original and/or basic concern

8. Look for alternatives
9. Be open minded
10. Take a position (and change a position) when the evidence and reasons are sufficient to do so.
11. Seek as much precision as the subject permits
12. Deal in an orderly manner with the parts of a complex whole
13. Use one's critical thinking abilities
14. Be sensitive to the feeling, level of knowledge, and degree of sophistication of others

Some of these dispositions relate to learning style, e.g. *Deal in an orderly manner with the parts of a complex whole* suggests a systematic approach rather than an exploratory approach and this was one of Kyllonen and Shute's dimensions of learning style. *Take into account the total situation* and *Keep in mind the original and/or basic concern* suggest a position within the *holistic processing ---- serial processing* learning style dimension. The relationship between dispositions and learning styles is elucidated by reference to Pask (1976) who devised categories for learning styles where some students were "disposed to act" like holists, others like serialists and others were categorised as versatile since they were able to act in either way depending on the subject matter. Pask's categories only addressed one dimension of learning style and were therefore too limiting for the purpose here. However his suggestion that some students were "disposed to act" in particular ways suggested that dispositions could be viewed as components of learning style. Ennis's list can be treated as a more detailed description of the aspects of learning style that are most appropriate for critical thinking.

All these dispositions can be useful for modelling, but some need to be adapted to make them more specific to the modelling process as defined in the framework (Figure 9.1). For example, item 7 could be rewritten as "Keep in mind the original purpose of the model", and item 11 could be rewritten as "Seek as much precision as the subject permits and the purpose of the model implies".

In addition, the following five dispositions are important for modelling:

15 Seek a clear understanding of the modelling metaphor as it applies in the situation being modelled.

16 Expect models to be imperfect.

17 Be prepared to experiment.

18 Look for inconsistencies.

19 Look for similarities with other problems.

Finding a way of measuring the occurrence of these dispositions in students carrying out modelling tasks is difficult but observations suggested that those students who were successful in their modelling tasks showed some evidence of these dispositions. The two students who worked on the "Bones" exercise outlined earlier certainly displayed some of these dispositions particularly:

4 Use and mention credible sources. (They referred to several books.)

5 Take into account the total situation. (They kept referring to the model skeleton to see where the bone fitted and how it could be identified.)

7 Keep in mind the original purpose of the model. (All the way through they were focusing on advice to help people identify a bone.)

11 Seek as much precision as the subject permits and the purpose of the model implies. (They made a lot of effort to distinguish between all the different bones and to ensure that their rules led to precise identification.)

12 Deal in an orderly manner with the parts of a complex whole. (They started at the top of the body and worked down systematically and the arrangement of their model on the screen was also systematic although arranged horizontally.)

17 Be prepared to experiment. (They tried out ways of structuring the model.)

18 Look for inconsistencies. (They kept testing the model to see whether it worked in the way they expected.)

19 Look for similarities with other problems. (Within this particular model they were looking for similar rule structures e.g. some bones could be identified by the bones at each end, others could be identified by position and function.)

Evidence for the other dispositions was not identified although there was no evidence that any of these dispositions were not being employed.

Students who were less successful in modelling were sometimes failing to show some of these dispositions. In particular, those who became confused about how to structure the model and make use of the modelling metaphor usually did not:

- Seek a clear statement of the thesis or question.
- Look for inconsistencies.
- Seek a clear understanding of the modelling metaphor as it applies in the situation being modelled.

In summary, critical thinking and modelling have been seen to have common elements. Ennis's taxonomy was intended to provide a set of goals for a critical thinking / reasoning curriculum more along the lines of Bloom's taxonomy rather than as a research tool to characterise learning skills as with Kyllonen and Shute's taxonomy. Ennis was attempting to characterise a practical process that was not necessarily primarily concerned with learning. When students were using one of the intelligent tutoring systems considered by Kyllonen and Shute they could be expected to perceive their goals as learning certain skills. But students using critical thinking are likely to perceive their situation as one where the aim was to solve a practical problem. Modelling is more akin to critical thinking in this context because the modelling activity has a purpose that the students may perceive as providing solutions for other people and the learning is a bi-product of the modelling process. Ennis's taxonomy offers some pointers towards goals for a modelling curriculum.

The identification of dispositions is particularly relevant to modelling capability. Students who were successful in modelling tasks showed some of the dispositions that were identified as important for modelling and students who were less successful were observed to lack certain dispositions. In particular they failed to seek a clear understanding of the problem and the modelling metaphor. There is a temptation to simply regard this as a reflection of students' general ability. Yet during these studies at least two students, who were identified as achieving significant success in modelling and who demonstrated some of these dispositions, were considered by their teachers to be of relatively low "general ability". The list of dispositions identified here represents a first step towards defining specific dispositions that are important for any type of modelling including computer based modelling.

9.5 Applying Sternberg's componential sub theory of intelligence

The two taxonomies discussed above both contained features that were appropriate for a taxonomy of computer based modelling. Neither was completely adequate. Sternberg's (1985) approach, which was outlined in Chapter 3 (Section 3.10), was different because rather than developing a taxonomy of learning or thinking skills his purpose was to develop a theory of intelligence. An advantage of his approach was that it focused on the higher order thinking processes that are required in computer based modelling as well as in other aspects of intelligent performance.

The stages in the modelling process were analysed in order to identify the metacomponents and then the classroom activities were examined for evidence of these. It was found that Sternberg's componential sub-theory did provide a basis for a rational analysis of the modelling process. It was possible to identify actions carried out by pupils and elements of the pupils' discussions that suggested that certain metacomponents were used. These metacomponents have been incorporated into the proposed taxonomy of modelling which is shown in Table 9.1 (page 305). They are parts of mental processes and so pupils' actions and talk are only indications of their use.

Sternberg applied his sub-theory to intelligence tests where particular test items were identified as indicating the use of certain metacomponents. Therefore having proposed a componential theory he was able to subject it to rigorous testing. This kind of evidence is not available in the normal classroom situation. Nevertheless the use of some metacomponents could be inferred from the pupils' actions in the modelling environment and their discussion.

The identification of the metacomponents in the modelling process was a first step in the development of a componential theory of computer based modelling. A further step would be to determine how they might be used in specific tasks and to devise tasks to test these models based on the theory.

The use of Sternberg's componential subtheory did help to characterise some of the mental processes that are important when people are building models and to identify some of the reasons for failure. It is also proposed that the failure to operate some of these metacomponents may be due to a lack of the appropriate disposition rather than an inability to employ a particular metacomponent. The idea of a "disposition", as put forward by Ennis, was discussed in Section 9.4. If someone is not disposed to seek similarities, for example, they are unlikely to identify them.

9.6 The social context

All three of the taxonomies examined here failed to take into account the social context of learning. The teachers in this study considered cooperation in groups to be an important aspect of the learning situation. This is in line with what is considered to be "good primary practice" as recommended by teacher trainers and local authority advisers to be the prevailing orthodoxy (Alexander 1988). This cooperative working also reflected real world situations in research and business where the importance of working in teams to solve problems had recently been emphasised in the United Kingdom bringing it more into line with practices in Germany and the United States. Many UK companies were adopting approaches to management training such as the Coverdale System about which Harvey-Jones (1988) commented: *"you learn that in* *teams each of you has a role to play and it is not always the most obviously well-equipped who can best work out the problem*".

In the following extract where pupils were developing skills in structuring the diagram, the instructional environment would be classified as analogy, according to Kyllenon and Shute, but it was the discussion between the two boys that enabled them to identify the analogy and define the structure precisely.

Keith	*So what do we do now?*
Dean	*We need another AND there* (pointing rather imprecisely at screen).
Keith	*Another AND there?* (pointing.)
Dean	*Yes like we did there* (pointing at a similar rule structure).
Keith	*Oh.*
Dean	*Last time we had an AND there* (pointing) *and another AND there (pointing).*
Keith	*No we put one AND up here then?* (pointing.)
Dean	*You can't get. I think we'll have to cos you can't get a thing through* (boxes quite close together) *there and you don't want to -*
Keith	*Well we can move that* (pointing).
Dean	*OK move it about here* (pointing).
Keith	*Just snip it.*

The interaction between the two boys added a further dimension to the learning situation which is important when classifying learning skills. In this case they were interacting by communicating verbally, by pointing to the diagram and through actions each performed on the model. Similar interactions reported in Chapter 8 (Section 8.2.5) show that the social interaction important in learning was clearly evident in these modelling activities.

Many researchers have studied and attempted to analyse social interaction (e.g. McAteer et al (1991), Dimant and Bearison (1991)). Dimant and Bearison's analysis would not capture the non-verbal communication and in this respect McAteer's proposal had advantages but it would be necessary to identify which categories were important for learning to take place if this were to provide any useful comparisons of computer based activities. For this research it is practical to use broad categories to characterise the type of social interaction:

- none

- cooperation where pupils are working together on the same task
- collaboration where pupils divide the task into sub-tasks which each completes and they then come together to join the parts into the finished product
- competition where each pupil is intent on completing the task individually but may interact to exchange ideas, etc.

In the modelling activities in Schools A, B and C pairs of pupils were generally working cooperatively but at times they changed to a collaborative style, usually for a limited time. There was also collaborative working at the level of a larger group on occasions when the whole class collaborated to produce parts of the model. There were differences between the groups as to how well the cooperation worked in that some pupils were able to communicate better than others. One of the problems was that pupils often did not receive any response from their peers or they received an inappropriate response to a question or suggestion. In order to characterise these differences it may be appropriate to use Noreen Webb's approach (Webb, 1984) which used categories such as *asks question, receives response* or *asks question, receives no response.*

In summary, there is a need to take account of the social context in a taxonomy of computer based modelling. This was missing from all three of the taxonomies that were examined. The approach that is suggested here uses broad categories to characterise the types of social interaction.

9.7 Defining a taxonomy of modelling

The three categorisation schemes outlined in this chapter all went some way towards characterising the skills and processes involved in modelling. Kyllonen and Shute's approach enabled a modelling activity to be characterised in terms of at least some of the learning skills that were practised. This taxonomy was relatively easy to apply but there were important omissions from this taxonomic approach including the social interaction and learning styles. This taxonomy attempted to characterise the process of learning as well as the results of the learning process. It is possible, as has been shown here, to apply the taxonomy to a modelling activity and to identify some of the learning skills practised by the group. It may be possible to add social interaction as another dimension by using the broad categories outlined earlier. An adaptation of this taxonomy would be valuable in a research context in order to compare different modelling activities and perhaps also to compare a wider range of learning activities. The taxonomy would also be useful for curriculum design work. The procedure is fairly time-consuming so the investment would be unlikely to be worthwhile in the school context. However, where significant investment was being made in developing computer based learning environments, whether in higher education or in training for business, this taxonomic approach would be worthwhile to determine the learning skills and processes developed by the software.

Ennis's taxonomy provided a set of goals for a critical thinking/reasoning curriculum. The major limitation of Ennis's taxonomy as it was described in his paper was that it was exemplified by the rather specialised situation of the courtroom for which it was developed. This situation is complex and many of the abilities required were too advanced for the pupils in these classroom studies. An interesting feature of Ennis's taxonomy was the inclusion of dispositions and the amended list given earlier is appropriate to contribute to the framework of a modelling curriculum.

Sternberg's componential subtheory provided a basis for a rational taxonomy of modelling skills in which the elementary information processes within the modelling process could be described on a theoretical level. Transcripts of the tapes of the activities together with notes have provided evidence for the use of particular metacomponents at different stages in the modelling process. This method of analysis is suggested to be most promising for defining the cognitive processes that are required for modelling. This could also ease the identification of problems which pupils are encountering in modelling and the determination of which metacomponents they may be lacking. A componential theory could be applied both to individual and group working. In the latter case components would be seen in a socio-cognitive environment.

The three approaches applied in this chapter have been developed for different purposes and therefore have different uses and applications. Kyllenon and Shute's taxonomy was intended principally as a research tool for characterising learning activities and for suggesting fruitful research directions, Ennis's taxonomy provided goals for a curriculum and Sternberg's componential subtheory was essentially a basis for analysis that could provide a componential theory that was similar to a taxonomy. All these have some relevance to modelling as a learning activity but in order to define a taxonomy of computer based modelling skills it was necessary to consider how such a taxonomy might be used.

A taxonomy of computer based modelling that would be of use to teachers and others who were interested in defining a modelling curriculum should:

- enable a comprehensive set of skills, abilities and dispositions that are required for modelling to be defined
- provide a description of a set of cognitive abilities that are required at each stage in the modelling process
- be applicable to all types of computer based modelling
- assist in the design of modelling activities by revealing which aspects of modelling and which stages in the process required higher level cognitive skills
- help to reveal how progression in modelling capability could be achieved.

This represents a combination of aspects of the taxonomic approaches that have been discussed in this chapter. The process of designing, building and evaluating a model was specified as a number of observable steps, some of which are iterated (see *Figure* 9.1). The thinking, interaction and decision-making can be characterised, as shown in Table 9.1, by further breaking down the process into a set of modelling dispositions, a set of general metacomponents required for all steps in the process and a set of specific metacomponents needed for particular steps in the process and a set of social skills.

Dispositions, general metacomponents and social skills apply throughout the modelling process. Other metacomponents are specific to particular steps in the process.

This analysis is intended to highlight those skills, abilities and dispositions that are essential and fairly specific to modelling. It facilitates the elucidation of a computer based modelling curriculum. Using this list teachers can decide what skills and abilities need to be developed in order to advance computer based modelling capability. Teachers can also determine some of the skills and abilities that are likely to be developed by a computer based modelling activity. In this case the list is incomplete, for example, the knowledge acquisition components identified by Sternberg that are essential for any learning situation are omitted. This is because teachers are likely to foster their development in a variety of other learning situations. This list of components should be used together with a more general list if teachers are intending to use modelling activities as a major part of the whole learning environment. Performance components are omitted because, as stated by Sternberg, they are considered to be less fundamental than metacomponents. Some practical manipulative skills are also needed for computer based modelling but these tend to be software specific and the design of new software should obviate their need so that it can be manipulated by all users, including those with physical handicaps. Social skills are included because although they are not specific to computer based modelling it is important to emphasise that educational modelling activities should involve cooperative team work as most modelling projects would in the real world. Although many schools in the UK do now emphasise cooperative working this is by no means universal. The list of social skills defines the key areas of social skills and these could be further classified into sub-skills. Throughout the modelling process it is assumed that children will be interacting and many of the metacomponents listed for the various stages will result from a complex series of social interactions.

Table 9.1 Components which contribute to computer based modelling

Dispositions

1. Seek a clear statement of the thesis or question.
2. Seek reasons.
3. Try to become well informed.
4. Use and mention credible sources.
5. Take into account the total situation.
6. Try to remain relevant to the main point.
7. Keep in mind the original purpose of the model.
8. Look for alternatives.
9. Be open minded.
10. Take a position (and change a position) when the evidence and reasons are sufficient to do so.
11. Seek as much precision as the subject permits and the purpose of the model implies.
12. Deal in an orderly manner with the parts of a complex whole.
13. Use one's critical thinking abilities.
14. Be sensitive to the feeling, level of knowledge, and degree of sophistication of others.
15. Seek a clear understanding of the modelling metaphor as it applies in the situation being modelled.
16. Expect models to be imperfect.
17. Be prepared to experiment.
18. Look for inconsistencies.
19. Look for similarities with other problems.

Metacomponents

General Metacomponents

1. Decide just what the problem is that needs to be solved.
2. Select lower-order components - choose a set of components to use in the solution of a task.
3. Select one or more representations or organisations for information.
4. Select a strategy for combining lower-order components - decide which order to use the components in and to what extent each should be used.
5. Decide allocation of attentional resources for thinking - decide how much time to spend on each component.

6. Monitor the solution - keep track of what has been done, what you are currently doing and what needs to be done.
7. Be sensitive to external feedback - understand feedback, recognise its implications and act upon it.

Metacomponents that are specific to steps in the modelling process

Step 1 Identify area of interest

1. Reflect on what you know.
2. Know the limits of your knowledge.
3. Identify gaps in your knowledge.
4. Construct mental representations.
5. Identify mental representations.

Step 2 Define the problem

1. Select a specific problem for modelling.
2. Decide on the nature of the problem to be modelled.
3. Decide whether a problem is susceptible to modelling.
4. Identify mental representation of other similar problems which have been modelled.

Step 3 Decide the scope, boundaries and purpose of the model

1. Identify/create a mental representation of how the model will be used.
2. Identify/create a mental representation of the model in a context.
3. Select a mental representation of a modelling environment.
4. Identify mental representations of other similar models.
5. Create a mental representation of the structure of a key part of the model using the metaphor of a modelling environment.
6. Identify serious problems in structuring the model using the metaphor of a modelling environment.

Step 4 Build the model

1. Decide on the basic structure of the model.
2. Identify a mental representation of the inference mechanism.
3. Identify similarities to mental representations of other similar models or parts of models.
4. Identify the main factors or variables.
5. Decide the relationships between factors or variables.

Step 5 Test the model

1. Recognise important elements of the model's structure which will determine how it behaves.

2. Identify/create a mental representation of a scenario in which the model might be used.
3. Identify sets of data as answers.
4. Select a mental representation of the expected output of the model.
5. Identify mismatch between the output of the model and the mental representation of the expected output.

Step 6 Evaluate the model
1. Decide to what extent the output of the model is adequate for its purpose.
2. Decide whether the output of the model can be improved.
3. Decide how much time and resources would be involved in improving the model.
4. Decide whether the investment of time and resources would be justified.

Social skills
1. Listen to peers.
2. Communicate ideas to peers.
3. Negotiate with peers.
4. Co-operate with peers.

9.8 Towards a curriculum for computer based modelling

The "modelling curriculum" should develop modelling ability as well as allowing for the learning of other subject matter through modelling. The list of components of computer based modelling defines the skills, abilities and dispositions that are needed for successful modelling. This list is intended to indicate to teachers the skills and dispositions that need to be fostered but it does not reflect the order in which these should be developed. It is expected that generally the curriculum should be a spiral one in which skills and dispositions are introduced when pupils are ready and are re-emphasised at appropriate points. The specification of metacomponents for different stages in the modelling process suggests that stages 1 to 3 of the process require a wider range of metacomponents including a number of general metacomponents. This was reflected in the approach taken by most teachers who carried out steps 1 to 3 themselves, involving the pupils by some class discussion. However, the studies, described in Chapter 8, showed that it is possible for some pupils at nine years old to undertake the whole modelling process successfully themselves provided that they are working with subject matter with which they are familiar and knowledgeable. This is in accordance with a number of studies discussed in Chapter 3 (Section 3.3). Donaldson (1978), cited studies that she used to support the view that children are capable of inference at a much younger age than would be expected according to Piagetian stage theory but that the nature of the subject matter is of critical importance. It follows that the development of modelling ability will be heavily context dependent so that if a learner is able to undertake the modelling process successfully in one domain (s)he will not necessarily be able to do so in another. However, even with excellent knowledge of the subject matter a modeller is unlikely to be very successful unless (s)he has appropriate dispositions, can deploy relevant metacomponents and can follow through the modelling process. Computer based modelling capability then is unlikely to show a linear progression through levels of modelling skills. Children can be expected to show competent modelling ability when tackling some modelling tasks but require a great deal of help in others.

Activities based on subject matter with which pupils are familiar and knowledgeable may be good starting points for developing basic modelling skills and abilities and for encouraging pupils to follow through the modelling process including the evaluation of their models. Pupils who have acquired some basic skills, abilities and dispositions, in this way, may then be able to tackle a modelling task based on less familiar subject matter where an important aim of the task is to develop understanding of the subject matter. Another approach that was favoured by the teachers in this study is to embark on a modelling task involving subject matter with which the pupils are unfamiliar and to structure the task so that the pupils undertake only parts of the modelling process and the teacher takes them through the more difficult aspects particularly the early stages of the process. Both of these approaches ensured that pupils' early encounters with computer based modelling involved building parts of the model. This contrasts with the starting point for computer based modelling contained in the National Curriculum (Department of Education and Science and the Welsh Office, 1990) which stated that pupils working towards level 4 should be taught to:

> *"analyse the patterns and relationships in a computer model to establish how its rules operate; change the rules and predict the effect."*

It is probable that this starting point was arrived at because it was considered too difficult for pupils at key stage 2 to undertake to build their own model and this was probably true until recently because there was no suitable software. However it would be easier for pupils to understand the patterns and relationships in a computer model if this were one that they had been involved in designing and building rather than trying to "guess" the basis of the model that is built into a simulation program by examining the output under different circumstances, as this statement from the National Curriculum suggests. The activities discussed in Chapter 8 (Section 8.1.1.1) where pupils built their own models showed that it is possible for children to undertake all the steps in the modelling process. This approach also provides a sense of ownership that increases motivation and enhances children's determination to tackle problems that they encounter.

At the same time as learning to build simple models the pupils could also be learning something of the modelling process and the nature of models. This is not to deny that pupils should have opportunities to examine and run more complex models. Such simulation activities can be valuable, for example, for pupils to ask "what if" questions when exploring the behaviour of systems that are difficult to study at first hand. This research does suggest however that pupils can be introduced to the modelling process and can construct their own qualitative models at an earlier stage than is suggested by the National Curriculum. This will have the benefits of enabling pupils to develop computer based modelling capability and enhance pupils understanding of the nature of models and hence reduce the risk of pupils assuming that models always provide the "right" answer.

Teacher intervention is important when pupils are undertaking computer based modelling activities. In this study there was a significant amount of teacher intervention, which was discussed in Chapter 8 (Section 8.2.7).

9.9 Summary and conclusions

In this chapter the modelling activities undertaken in the classroom evaluation have been reviewed with reference to the description of the modelling process that was presented in Chapter 2. In the modelling activities in this investigation the teachers usually identified the problem to be modelled and explained the problem and the purpose of the model to the pupils so the teachers were therefore carrying out steps 1 to 3 of the modelling process. However experience in School C suggested that pupils could undertake the whole modelling process in areas in which they were already interested and knowledgeable.

Three approaches to defining modelling abilities were investigated: Kyllonen and Shute's (1989) taxonomy of learning skills, Ennis's (1987) taxonomy of critical thinking dispositions and abilities and Sternberg's (1985) componential subtheory. The three different approaches were applied to the modelling activities recorded in the classroom. Each approach provided a partial characterisation of modelling activities but none was completely adequate. Therefore a new taxonomy of computer based modelling has been proposed, which contains elements of each of these approaches and is intended to be of use to teachers, researchers and others who are interested in analysing or defining a modelling curriculum.

This taxonomy defines the skills, abilities and dispositions that need to be fostered for successful modelling. It is proposed that the curriculum should be a spiral one in which skills and dispositions are introduced when pupils are ready and are re-emphasised at appropriate points. This would enable the importance of context to be taken into account. In contrast with the starting point for computer based modelling contained in the National Curriculum (Department of Education and Science and the Welsh Office, 1990), it is recommended that pupils' early encounters with computer based modelling involve building parts of the model thus enabling them to develop both modelling ability and understanding of the modelling process.

Chapter 10 Conclusions and Further Work

In this chapter the main conclusions from the thesis are summarised and their implications are discussed. The limitations of the research are acknowledged and discussed. Suggestions are made for future work that could be done, both on the evaluation of qualitative modelling using Expert Builder and to develop the software itself and other similar software. In addition some more extensive investigations which would build on this work are suggested.

10.1 Overview

This research has demonstrated that it is possible for pupils aged eight years upwards to use computer based qualitative modelling techniques to develop models on a variety of topics. The skills and abilities required for computer based modelling have been identified and characterised. Criteria which can be applied to a computer based modelling curriculum have been defined. The findings of this research question the progression in computer based modelling skills and abilities that was specified in the National Curriculum for England and Wales (Department of Education and Science and the Welsh Office, 1990). The research has produced a design for an environment in which qualitative models based on rules can be constructed. The design is based on empirical evidence of children modelling as well as on theoretical grounds. A prototype of the environment was implemented in Microsoft Windows by programmers on the Modus Project. A survey of initial impressions from users of the software showed that a wide range of different potential users in education could envisage opportunities for using the software across a range of subjects. These users could conceive of benefits to pupils' learning through modelling in this environment.

A detailed study of primary school pupils using the modelling environment within the classroom and in the context of their normal curriculum work showed that the software was suitable for classroom use. The findings of this study have contributed in four areas: to the practical use of IT in education, understanding of the skills and abilities required for modelling, defining the modelling curriculum and the methodology of educational software design. These findings are summarised in Section 10.2 and discussed in subsequent sections.

10.2 Summary of research contributions

The main contributions of this thesis may be summarised as follows.

- It has provided a new approach to computer based modelling for schools, using a graphically-oriented qualitative rule-based method. The formative evaluation of the prototype modelling environment demonstrated that this approach can be applied in typical classroom settings. This has generated modelling opportunities in geography and history as well as extending the possibilities in other areas such as science, technology and mathematics.
- The formative evaluation showed that it is possible for some pupils as young as nine years old to undertake the whole modelling process successfully themselves provided that they are working with subject matter with which they are familiar and knowledgeable.
- Qualitative modelling, using Expert Builder, encouraged cooperative working because the task of building a model as a diagram in this environment meant that the activity was split between manipulating the mouse and typing text so two pupils could be involved simultaneously in building the model. The classroom study provided evidence that pupils worked in this way without being instructed to do so and there was a high level of on-task pupil-pupil interaction. The learning style was "active" in line with that promoted by Piaget and others, as discussed in Chapter 3 (Section 3.5).
- A set of goals for developing computer based modelling ability has been defined, based on an analysis of the modelling process and evidence from the classroom investigation. This analysis applied ideas and methods from three taxonomic approaches to learning, those of Kyllonen and Shute (1989), Ennis (1987) and Sternberg (1985). These goals for developing computer based

modelling ability could assist teachers in deciding what skills and abilities need to be developed in order to advance computer based modelling capability and help them to plan appropriate modelling tasks.

- The formative evaluation suggested that the subject matter of a modelling activity affects the extent to which pupils are able to undertake the modelling process. The computer based modelling curriculum should therefore be a spiral one, providing pupils with opportunities to develop models on a variety of topics. Skills and dispositions should be introduced when pupils are ready and re-emphasised at appropriate points.

- Expert Builder was designed by the author to enables users, including primary school children, to construct models on a range of subjects. The design is based on a simple rule-based metaphor presented through a diagram. Other software environments have used rule-based metaphors but Expert Builder is unique in two important ways. First the design incorporates features that are essential for *beginning* to build models. Secondly the design incorporates the principle of naive realism (DiSessa 1986) so that the whole structure and function of the environment is presented visually to the user and (s)he can interact with this visual presentation.

- This research used a methodology for designing and developing educational software which took full account of technological developments and considerations but was led by educational needs. This methodology would be a good model for future developments in the use of computers in education that involve substantial innovation.

- A literature review on aspects of learning theory and practice that are relevant to computer based modelling was presented and used to establish a set of criteria for the design of the software and to discuss how such software could be integrated into the classroom learning environment.

- A literature review on computer based modelling systems and metaphors that were relevant to the design of a computer based qualitative modelling environment was presented. This identified possible metaphors for a new environment.

- A "test of competence" in using Expert Builder was developed. This revealed important information about pupils' mental models of the modelling metaphor and the kinds of mistakes which they made in using it.

10.3 Contribution to information technology in education

In this section the contributions made by this project to information technology in education are discussed in relation to the situation existing in the UK, relevant national initiatives and other studies.

10.3.1 IT across the curriculum

This research has contributed to the incorporation of computer based modelling as an aspect of IT capability that can be developed across the curriculum. This is an area where there is some confusion and a need for further development. In England and Wales it has become accepted that, in general, the use of IT should be integrated across the curriculum rather than being taught as a separate subject. This approach resulted primarily from initiatives undertaken under the Microelectronics Education Programme (MEP 1981-6) and by various LEA advisory teams and is based on two main principles. First the belief that using IT can enhance children's learning of other curriculum subjects and second the importance of developing IT skills and capabilities in meaningful contexts of relevant uses and applications. These ideas were embodied in the National Curriculum for England and Wales (Department of Education and Science and the Welsh Office, 1990) that promoted the use of IT across the curriculum.

The attainment target for IT Capability in the National Curriculum was included as one of the Technology attainment targets but the non-statutory guidance stated that pupils should be able to use IT across the whole curriculum. This led to some confusion and a call from teachers and various organisations, including the National Council for Educational Technology, to re-define IT capability across the curriculum (Dearing 1993).

The HMI report (HMI 1992), based on the time when schools were beginning to implement National Curriculum requirements, stressed the importance of the relevant use of IT and integration within the curriculum:

> *"The National Curriculum has promoted a change by specifying work with IT which reflects the range of more common applications found in the world outside school and higher levels of attainment which require a far from superficial treatment."*
>
> *"As in other aspects of the curriculum, schools vary in the extent to which they hold to the acquisition of skills perceived as serving the needs of employment; many of the skills acquired are certainly marketable although it is a limited view to see this as the sole rationale."*
>
> *"The best teaching with IT makes use of the opportunities offered to change the ways in which pupils and teachers approach tasks and solve problems."*

Despite the fact that IT had been available to schools for about ten years and its use had been promoted by several government initiatives, the use of IT in schools in 1993 was still limited and its extent variable. The ImpacT study (Watson et al., 1993), for example, encountered difficulty, when selecting schools for their research, in finding enough schools that were making regular use of IT in english, mathematics and science. The most frequent subject-focused use of IT in primary schools was in mathematics and english and at the secondary level in IT and business studies.

The National Curriculum attainment target for IT Capability included five strands, communication, information handling, data logging and control, modelling and applications and effects. Evidence from the HMI study (HMI 1992) suggested that these had not been equally well implemented and modelling was one of the areas that was causing difficulty. HMI reported that the great majority of lessons concentrated on word processing and graphics; aspects of IT such as sensing and control, exploring computer models and understanding the social implications of IT received scant attention. HMI also reported the uncommon use of simulations and the fact that it was very rare to attempt to examine the basis of the model itself. They stated that:

> *"there is a need for more software which would allow pupils and teachers to explore changes in the algorithms and assumptions of simulations." "Packages such as electronic spreadsheets can be used for modelling and predicting but are used almost exclusively for calculating."*

The Dearing report (Dearing 1993), which examined the implementation of the National Curriculum, concluded that basic IT skills must be rooted securely at the heart of the National Curriculum so it was likely that future changes to the National Curriculum would emphasise the cross curricular use of IT.

There was a need to develop further the use of IT in schools and one requirement, which had been identified, was to provide opportunities and facilities for computer based modelling. This research has shown that a style of computer based modelling is possible in which learners can express problem solving and decision making strategies by constructing models based on qualitative rules. The type of qualitative modelling, developed in this research, represented a new approach for schools who were previously restricted to modelling with spreadsheets and Logo and some advanced level modelling with dynamic modelling environments. The latter was mostly based in mathematics and science. The qualitative approach opened up modelling opportunities in geography and history, some of which were demonstrated in the classroom investigation discussed in Chapter 8. At lower levels it provided opportunities for a different style of modelling that complemented Logo work.

Results from the "Tools for exploratory learning project" (Bliss et al., 1993), which took place at the same time as work reported in this thesis, also upheld the value of qualitative modelling as an approach for learners. This research supports the suggestion that using a computer based modelling system can provoke ideas that can be built on, especially where pupils have made their own models. Pupils of 11-14 were able to engage in modelling tasks of reasonable complexity including both exploring and constructing models. All the pupils could construct a model, even if limited, with all three types of tools but the more pupils knew qualitatively about a topic the less easy it was for them to regard a quantitative model as useful, and the more difficult they found it to use their knowledge to build a quantitative model.

10.3.2 Qualitative modelling in the classroom

In the classroom study, discussed in Chapter 8, models were constructed on widely varying subjects and the model structures were varied. A majority of the models were advisory models, based on the classification discussed in Chapter 2 (Section 2.7.2.1), but there were also some classification and diagnostic models. Both teachers and children had little difficulty in finding opportunities for using qualitative modelling. The teachers, in the detailed study, discussed in Chapter 8, were able to identify problems or situations to model in each of the topics that they were covering. All those who returned questionnaires in the survey discussed in Chapter 6, suggested a number of areas for modelling. Pupils were able to suggest topics on which they wanted to build qualitative models after a brief demonstration of the software. Constructing or adding to a model provides an active task in which learners are selecting and reorganising their knowledge. In some of the situations observed this involved using recently acquired knowledge and hence consolidating learning and understanding, while in other situations it provided a stimulus for pupils to find out information from books.

Qualitative modelling using Expert Builder encouraged cooperative working because two pupils could be involved simultaneously in building the model, one of them positioning and linking boxes and the other typing the text. The task of building a model as a diagram in this environment meant that the activity was split almost equally between manipulating the mouse and typing text. The screen view of the model helped the pupils to communicate their intentions by pointing at the structures and a high level of non-verbal communication was involved. This corresponded with Noreen Webb's conclusion (Webb, 1984) who suggested that the learning medium - the computer, is very different from other classroom learning media in that the strategies or approaches and results are clearly seen by everyone because they appear on the screen in a standardised fashion so pupils can learn from what other group members *do* as well as from what they *say*.

10.3.3 The modelling metaphor

The metaphor obviously imposed some restrictions on modelling just as any metaphor would. It was intended that the tool would be applicable in a range of situations and this was verified by the classroom investigation, discussed in Chapter 8, and the questionnaire survey discussed in Chapter 6. Clearly, an application had to make use of the metaphor, i.e. it had to be designed to provide advice, give a diagnosis or to draw a conclusion based on the conditions at a particular point in time. Teachers in this study became aware of this requirement and designed tasks accordingly. A significant minority of the pupils also became able to structure and develop models without help and they were therefore using adequate mental models of at least some aspects of the modelling metaphor. Most used rule structures which they had been shown but some experimented and found other structures. There was a range of expertise shown in developing mental models of the metaphor. Some, who were unsuccessful, did not even manage to identify and use a structure when it was on the screen in front of them. The pupils who were more successful in creating a model towards the end of the year were those who had been shown simple techniques at the start and had worked on their own models, experimenting with new techniques themselves and being introduced to other features of the system when they requested help.

10.3.4 Support for modelling

Expert Builder provided a metaphor that users, including primary school children, could use to construct models on a range of subjects. The diagram assisted the development of understanding of the metaphor as well as debugging of the models although there were some limitations that are discussed in Section 10.8. The tools rendered construction of models easy although again there were limitations, particularly in the use of the scissors and thread and in facilities for restructuring the diagram, which are discussed in Section 10.8.

It was also evident that modellers needed to have a clear view of the basic structure of their models at the start, otherwise creating a large number of boxes simply led to confusion. If the facilities for restructuring were improved it would be possible for modellers to create clauses as they thought of conditions and then to restructure the diagram later provided that they were clear about the general structure, including at least some of the advice clauses and the types of conditions.

10.3.5 Extent of use

The software was made available to any educational institution via the Modus club and about 140 educational institutions joined and obtained copies of Expert Builder. Feedback was received from primary and secondary schools, FE colleges, higher education institutions and advisory services but only about 15 of the members returned questionnaires. Evidence suggested that only a handful of schools made significant use of Expert Builder but it was concluded from comments made on questionnaires and from follow up phone calls that this was due predominantly to teachers' lack of time rather than to the inappropriateness of the software since comments about the software were generally favourable or expressing interest in the concept. A further reason for relatively limited use was identified as the lack of robustness and finish of the package which led IT coordinators to believe that it would be demotivating for inexperienced staff.

No further follow up was done and Expert Builder was not promoted further, after this questionnaire survey, because it was intended to improve the software following its evaluation and to publish a polished version. This was released in June 1993 and it is too early to comment on the extent of use of this version.

10.3.6 Modelling and learning

During the classroom investigation, discussed in Chapter 8, pupils were observed searching for information in books and there was evidence of strong motivation. The teachers viewed the modelling activities as opportunities for pupils to consolidate and extend their knowledge of the topics that they were studying. Although one of the principles behind the development of this software was that computer based modelling should enhance children's learning it was decided, early in this project, that no attempt would be made to measure this. Computer based modelling was intended to be a part of the whole learning environment and qualitative modelling was expected to provide new teaching and learning opportunities. Papert (1984) argued that attempts to measure the impact of learning to program on children's learning, which had yielded equivocal results, were based on too narrow a view of the learning environment. Qualitative modelling might be used in many different ways and would hence affect different learning outcomes. Attempts to measure specific learning outcomes in a new area, such as this, would either restrict the study or only capture a small proportion of its influence. In addition, in this study, the amount of use of the software by any individual child was quite low and would probably not have been sufficient to show clear effects. This view was supported by the ImpacT study (Watson et al. 1993), a major research project that set out to measure the effects of IT on pupils' learning. Statistical results, from the ImpacT project, were only able to demonstrate a very small contribution of IT to pupils' learning and only in some subjects. This difference was contributed mainly by a small number of "High IT" classes and suggested that there was some minimum threshold of IT use for the impact of IT to be detected. There was therefore no conclusive evidence that computer based modelling enhances learning of the subject matter more than other learning methods but it did increase motivation for some children and encouraged children to look up information and to clarify their ideas.

While this research was in progress the "Conceptual change in science project" (Draper et al., 1992) did examine some aspects of the contribution of computer based modelling to pupils' learning. This project focused specifically on using simulation and modelling software to bring about changes in students' understanding of mechanics, a topic where much research evidence has shown that students tend to "resist" teaching and to retain their own alternative mental models. A general conclusion of this research was that qualitative modelling enables students aged 12 to 13 to express, expose and to test their beliefs, thus creating conditions which are favourable for the cognitive conflict which has to accompany any belief change.

10.4 Contribution to understanding of the skills and abilities required for computer based modelling

In this research the process of designing, building and evaluating a model has been specified as a number of observable steps, some of which are iterated. It is argued, in Chapter 2, that this definition of the modelling process is applicable to any computer based modelling activity and provides a framework for learners and teachers.

In Chapter 9 the modelling process was analysed in relation to three taxonomies of learning, (Kyllonen and Shute (1989), Ennis (1987) and Sternberg (1985)) each of which contained elements that were appropriate for a taxonomy of modelling. The use of these three taxonomic approaches provided a basis for an analysis of the modelling process in order to highlight those skills, abilities and dispositions that are essential to modelling and fairly specific to modelling. From this analysis a set of components of computer based modelling ability have been defined that will assist teachers in deciding what skills and abilities need to be developed in order to advance computer based modelling capability. The thinking, interaction and decision-making were characterised by breaking down the process into a set of modelling dispositions, a set of general metacomponents required for all steps in the process, a set of specific metacomponents needed for particular steps in the process and a set of social skills.

10.4.1 Development of modelling skills and abilities

During the classroom investigation, discussed in Chapter 8, it was found to be important that the first modelling exercise set for pupils could be carried out successfully with a very simple rule structure. Showing pupils a model which had already been built probably gave them some feel for what the system could do but showing them how to build a few simple rules was more important.

This research showed that it is possible for some pupils at nine years old to successfully undertake the whole modelling process themselves provided that they are working with subject matter with which they are familiar and knowledgeable. As discussed in Chapter 9 (Section 9.8), this is in accordance with other studies that showed the importance of context in cognitive development. It was therefore concluded that computer based modelling capability is unlikely to show a linear progression through levels of modelling skills. Children would be expected to show competent modelling ability when tackling some modelling tasks but would require a great deal of help in others.

The earlier stages in the modelling process, which require a holistic approach and a diverse range of cognitive skills, were generally more difficult for pupils especially where the subject matter of the model was also relatively new. One of the key metacomponents, identified as crucial for successful model design, was "identifying similarities to mental representations of other similar models or parts of models". It is argued that expert modellers rarely start with a completely new design but look for analogies between the current problem and previous problems that they have modelled. The pupils who built models of their own created analogous structures to those that they had been shown. Results of the test discussed in Section 8.3, showed that some pupils were unable to recognise similarities between a new model and one that they had been shown even when the original was still on screen in front of them. This is an area that merits further investigation.

The view of modelling progression in the National Curriculum stated that pupils should progress from using models and simulations to building their own models but this research suggests that pupils would develop modelling ability more effectively by undertaking a series of tasks which involve building progressively more complex models. This suggestion is in accordance with results from the "Tools for exploratory learning project" (Bliss et al., 1993), which showed that pupils of 11 or 12 can make their own models and suggested that if they do so they will understand better that a model is simplified, fallible, can be changed and may need to be remade altogether.

10.4.2 Teacher intervention

As discussed in Chapter 8 (Section 8.2.7) Expert Builder gave feedback to pupils about whether their model was working as they intended but help was sometimes needed particularly when the model didn't behave as expected. Pupils made faster progress if the teacher showed them relevant facilities when the pupils asked how to do something or the teacher perceived a need for some instruction in how to use the software. The appropriate level and type of teacher intervention is very difficult to achieve but probably no more so than in other learning situations. In this case the particular problem on which the pupils were focusing was clearly visible on the screen and this enabled the teacher to assess the situation quickly. In order to be able to do this the teacher needed considerable familiarity with the software.

In this study there was a significant amount of teacher intervention, which was discussed in Section 8.2.7, but Eraut and Hoyles (1988) reported that generally teachers do not intervene when pupils are working at a computer, because pupils work on them for long periods without any signs of boredom or disturbance and this frees the teacher to attend to other pupils. This approach is inappropriate where the computer is being used to support open-ended work as with collaborative writing or computer based modelling. In the early stages of using a modelling environment pupils need help with using the software. This should take the form of regular checks to see that pupils are working reasonably efficiently with the environment. If such monitoring is not done pupils may make frustrating and time-consuming mistakes. A balance needs to be achieved between allowing pupils to experiment and preventing them from fruitless efforts. This type of intervention is relatively easy and can be achieved by a quick glance at the screen at intervals and short periods of instruction provided that the teacher is fairly familiar with the software environment. Another type of intervention is concerned with promoting modelling abilities and dispositions and is more time-consuming. The teacher can gain significant insight into the strategies the group is adopting from looking at the screen but will probably need to observe and question the pupils in order to determine what their intentions are and whether they are employing appropriate abilities and dispositions. Deciding what intervention is necessary presents the same complex dilemma as with any other open-ended learning activity. But the teacher may have more information available, in this situation, because the visual representation of the model on the screen can reveal more about the pupils' thinking than the products of most other group activities.

10.5 Defining the modelling curriculum

The "modelling curriculum" should develop modelling ability as well as allowing for the learning of other subject matter through modelling. The taxonomy of computer based modelling ability, outlined in Chapter 9 (Section 9.7), defined the skills, abilities and dispositions that are needed for successful modelling. This taxonomy is intended to indicate to teachers the skills and dispositions that need to be fostered but it does not reflect the order in which these should be developed. It is expected that generally the curriculum should be a spiral one in which skills and dispositions are introduced when pupils are ready and are re-emphasised at appropriate points.

As discussed in Chapter 9 (Section 9.8) pupils' early encounters with computer based modelling should involve building parts of the model. The provision of qualitative modelling facilities enabled younger pupils to design and build their own models. There is a place for using and interacting with models, built by others, in order to aid development of understanding of the situations that they model but "guessing" how a model works is an inappropriate goal for developing modelling capability and it may increase confusion. A more useful activity would be to evaluate the model by comparing outputs with real data or predicting outcomes from knowledge of the real situation. In this way pupils could become aware of the nature and limitations of models. In the National Curriculum, evaluation of models only appears at levels 9 and 10 which are only expected to be achieved by more able 14 to 16 year-olds. Research reported here suggests that this ability could be developed in primary school pupils and it is important in developing understanding of the nature of models.

Modelling is expected to contribute to other aspects of learning. Modelling activities may therefore be incorporated into classroom work in order to promote the development of understanding of other subjects. This was the primary aim of the activities in the classroom studies reported in Chapter 8. Teachers designing such activities need to be aware of the modelling abilities of their pupils. They need to design the activities so that the pupils progress in developing modelling ability as well as using modelling as a learning tool. This research has shown that there are opportunities for modelling in most areas of the curriculum and that such modelling is feasible for pupils aged about nine years and above. In some topics qualitative modelling may be particularly appropriate while in others a quantitative approach may be desirable. Early modelling experiences could involve qualitative modelling and should range over topics in humanities, science and technology. As pupils develop more mathematical skills it would be appropriate to introduce some quantitative modelling, either using a different modelling environment or, if the facilities of Expert Builder were extended, by adapting models that had already been built. The latter possibility is discussed in Section 10.9.

10.5.1 Resource implications

The modelling curriculum has implications for the provision of computer resources in schools. In this study pupils were very limited as to how much time they could spend using the software since there was only one computer available to a class of up to 32. In order to carry out a modelling task a pair of pupils needed to work at a computer for four or five hours in one-hour stretches. If they were to develop modelling skills they would need to undertake several such modelling exercises during a school year. Modelling is only one of the activities for which pupils need access to a computer. Ideally computers should be available so that the pupils could use one whenever they feel a need, e.g. when a group of pupils were tackling a task where constructing a model might facilitate their understanding or where a model might enable them to present their ideas. This would entail a significant increase in the level of computer resources over those generally encountered in this study.

The quality of the computers is also significant. Sophisticated and user-friendly modelling systems, such as Expert Builder, required relatively powerful computers compared with those that were generally available in schools. Those used in the study were barely adequate. As schools bought more equipment they would probably be acquiring more powerful computers and towards the end of the period of this research more schools possessed computers that were sufficiently powerful to run Expert Builder. However, if it is to take full advantage of opportunities of the increasing power of technology, educational software will continue to be developed for computers towards the top end of the personal computer range. Schools therefore need to maintain a high level of provision of relatively powerful computers in order to be able to provide opportunities for a range of open-ended computer based tasks including modelling.

10.6 Contribution to human computer interface design

Expert Builder incorporated several new design features that represented a contribution to user interface design for education. These are discussed in this section and in addition the choice of the modelling metaphor that was explained in Chapter 4 is discussed in relation to developments of computer based modelling environments that have taken place during this project.

10.6.1 Design of an interactive visual interface

An interface has been designed that enables the expression of qualitative rule-based models by means of a diagram constructed by mouse-controlled tools. Design decisions were discussed which gave the interface desirable properties.

- Rules can be constructed and chained together on the diagram so that users can see the structure of each rule and the relationships between the rules. In most other expert system shells rules are input separately and it is difficult for users to maintain a mental model of the overall structure of their models.
- The trace of the inference is shown on the diagram when the model is run so that users can debug their models easily.

- Models could be constructed in various ways; starting from the base of the screen and working upwards is equivalent to forward reasoning whereas starting from the top and working downwards enables goal directed reasoning. This is much more flexible than a system based on textual rules where one particular rule format is provided.

One of the key design principles was that of naive realism (DiSessa 1986) which states that it must be possible to present the whole structure and function of the environment visually to the user and enable them to interact with this visual presentation. A visual representation of both the rule structure and the inference mechanism was used to make the structure and function of models comprehensible. The human computer interface design and the design of the modelling metaphor were inseparable because it was necessary to identify a metaphor that could be fully presented visually to the user.

10.6.2 Design of the modelling metaphor

The design of Expert Builder did successfully enable the metaphor to be presented visually to the user and enabled her/him to interact with the visual display thus adhering to the principle of naive realism. The design was sufficiently simple to enable primary school children to make use of the software to build models and it was also found, from evidence discussed mainly in Chapter 6, to be useful for secondary school pupils pursuing IT courses at advanced level to build models as well as for pupils in further and higher education. The metaphor chosen was a very simple rule structure consisting of textual clauses which could be either true or false and could be linked together into rules of the form:

conclusion IF premise

where the conclusion is a simple textual clause but the premise can contain several clauses and the logical operators AND, OR and NOT. Restricting the rules to this simple structure with no variables, mathematical comparators or arithmetical operations enables visual presentation of the rule structure and links between the rules, whilst also allowing for a variety of types of expression. The other component of the metaphor is an inference engine based on a simple backward chaining mechanism with a depth first search strategy that starts from the left.

10.7 Contribution to the methodology of educational software design

In this section the methodology that was used for the design and development of the qualitative modelling environment is summarised and discussed with reference to its use for other developments of the use of information technology in education..

The software design process in this project took the following form:

1. Specifying criteria for the design by researching relevant theory and by seeking views of potential educational users.
2. Identifying a metaphor by considering possible metaphors with reference to the functional needs and the user interface criteria.
3. Prototyping design ideas and discussing them with potential users.
4. Producing a working prototype and enabling trialling by a wide range of potential educational users.
5. Evaluating the design and revising the software for publication.

This process was significantly different from the processes by which most software for education has been developed in two main ways. Firstly the extensive consultation on the design and secondly the widespread trialling and evaluation. This process was important for this venture because the initiative was in an area of computer use where schools and teachers had very little experience. Many educational software developments were less ambitious being modifications of systems that were already in use. Commercial educational software developers typically produced improved versions of existing generic software, e.g. educational word processor and spreadsheet packages or developed ideas for specific packages that had been supplied by teachers. Earlier developments in educational software did involve major curriculum development work, e.g. the Chelsea Computers in the Curriculum Project (Cox 1983) set up a team of teachers and software developers to develop ideas mainly for simulation software. The Advisory Unit for Microtechnology in Education also involved a large team of teachers and software developers and integrated curriculum and software development when developing software for information handling (Freeman and Levett 1986). The methodology used in the Modus Project was a development of these approaches in that it involved teachers and curriculum development work. The major difference was the important focus on interface design which had to inform the design of the metaphor. The increased power of the target machines, beyond that available for previous developments by the Computers in the Curriculum Project and the Advisory Unit for Microtechnology in Education, meant increased opportunities for visual presentation and this was the main area where additional design considerations and extra feedback were important. The methodology took full account of technological developments and considerations but was led by educational needs. The methodology is discussed more fully in Cox and Webb (1994).

The methodology used in this project would provide an effective model for developments in the use of computers in education which involve substantial innovation.

10.8 Criticisms and limitations

In this section criticisms and limitations of the research are acknowledged. Many of them are taken up in the extensions and further work sections.

10.8.1 Modelling limitations of Expert Builder

Expert Builder was designed to facilitate qualitative modelling particularly situations, problems or decisions that could be defined by rules. The classroom studies and other feedback revealed that this provided for a range of modelling opportunities but the following limitations were identified during the formative evaluation:

- inability to access tables
- inability to deal with events over time

- the layout of the diagram

and these are discussed in this section.

10.8.1.1 Inability to access tables

The facility to access tables would have been useful where users wanted to compare a number of entities, e.g. when selecting a hotel. Such models are quite common and although a database package could be used, the combination of a table/database facility and an expert system would provide a more powerful modelling environment. The provision of such a facility would require implementation of variables. This possibility was discussed in Chapter 5 but was rejected, for this version, owing principally to the difficulty of representing the system visually but also to technical difficulties. The scope for incorporation of variables in future versions is discussed in Section 10.9.

10.8.1.2 Inability to deal with events over time

This limitation is fundamental to this rule-based metaphor because it is a property of the underlying logic. In order to deal with time based models it would be necessary to use a completely different metaphor such as the story builder metaphor. One of the reasons for confusion related to this limitation was the left to right inference mechanism which suggested to some users that they might give a sequence of advice. In some cases this worked to the user's satisfaction but in others it led them to become embroiled in complex logic. The visibility of the inference mechanism was useful for debugging models and so it would not be appropriate to hide it in order to discourage users from adopting a procedural approach. The preferred option is to allow users to experiment with various ways of using the software but to provide advice in the documentation about possible pitfalls.

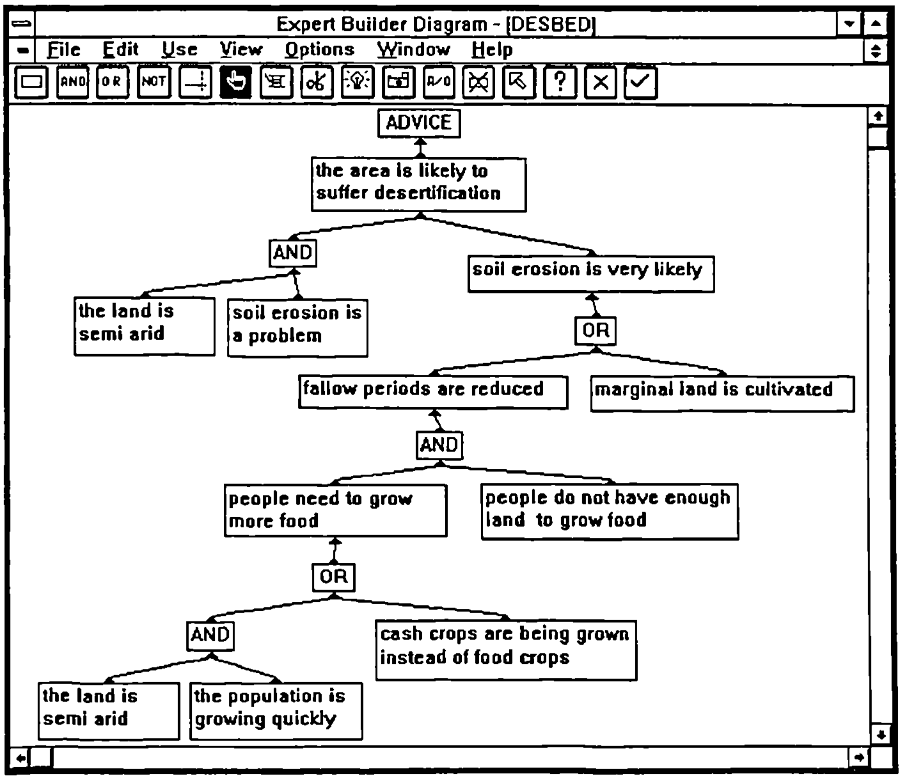

Figure 10.1 A model built by secondary geography pupils which made use of a chain of reasoning to model a series of events

Interestingly, during some further curriculum development work completed after the classroom investigation that was reported in this thesis, one teacher made use of a chain of reasoning to model a series of events. The model shown in Figure 10.1 was predicting the future rather than giving a series of pieces of advice and it successfully made use of the chaining facility. This model was built in Expert Builder 2 and it also illustrates how the arrows, discussed in Section 10.8.2, could make the expression of cause and effect clearer.

This use of the software demonstrates the great flexibility that can be provided by a simple metaphor and it provides one way of dealing with a chain of effects.

10.8.1.3 The layout of the diagram

Throughout the study a number of comments were made about the format used for the layout of the diagrams particularly with reference to the arrangement of rules with the conclusions at the top of the screen. Users who found problems with this arrangement were generally building models by starting with the conditions and reasoning forwards to the conclusions and they placed the conditions at the top of the screen. They found it difficult to accept the arrangement required by Expert Builder. There is insufficient evidence, from this research, to conclude that an alternative arrangement with conditions at the top would be better. The layout was chosen for reasons of expressivity. It was considered to be important to focus attention on the conclusions, which could be designated as advice, so that modellers were encouraged to consider the purpose of the model. In order to determine which arrangement would be easier to use, for a majority of users, it would be necessary to implement alternatives and compare their use in a range of situations.

10.8.1.4 Summary of modelling limitations of Expert Builder

Three specific limitations of Expert Builder as a qualitative modelling environment that were identified from classroom studies and other feedback have been discussed here. They were the inability to access tables, inability to deal with events over time and limitations of the layout of the diagram. Another aspect for consideration in relation to the modelling limitations of Expert Builder was how the use of this metaphor would compare with the use of other metaphors for modelling. It was obviously not possible to evaluate this from this study but, as was discussed in Chapter 8, the appropriate selection of the topic for modelling was an important element in the success of the modelling activity. Modellers matched their choice of task to their knowledge of the capabilities of Expert Builder and in this way this metaphor was found to facilitate a wide range of types of modelling. However this study did not necessarily reveal all the limitations of this modelling metaphor that might be revealed if a comparative study were possible. The choice of the metaphor was discussed in Chapter 4 and was based on a range of considerations including some limited evidence of other metaphors in use. The Modus feasibility study had enabled some small-scale investigations of pupils modelling with different software but a more extensive comparative study would be valuable and this is discussed further in Section 10.10.

10.8.2 Shortcomings of the implementation of Expert Builder

In this section limitations of the prototype version of Expert Builder, which was used during this research, are summarised and methods of improvement are discussed. In some cases the shortcomings were identified at the implementation stage but could not be overcome owing to resource and/or time constraints. These were discussed in Chapter 5. Other shortcomings were identified during the formative evaluation. Some minor improvements were made during the this research but more major changes were left until a major revision of the software. This revision was undertaken following the research described in this thesis and resulted in publication of Expert Builder version 2 (Webb et al., 1993). The improvements incorporated into Expert Builder version 2 are listed in Section 10.9.2.

The version of Expert Builder, implemented during this research, was a prototype to show the practicality of the design and to enable some classroom evaluation. The programming required considerable effort, taking about two programmer years in total. The program was not sufficiently robust and sophisticated for normal classroom use, i.e. with teachers who lacked confidence in using computers. The implementation served its purpose but the lack of certain facilities, which had not been implemented due to time constraints, and the occurrence of some bugs, limited its use in schools. The following were identified as aspects that had caused users some problems or where users suggested improvements:

- linking boxes
- cutting threads using the scissors
- sizing boxes
- printing
- facilities for restructuring the diagram
- nature of the links
- display of the reasoning used
- the amount of screen space for constructing the diagram.

10.8.2.1 Linking boxes

A minority of users experienced some difficulties in using the bobbin to link boxes. During the study the mechanism of linking was improved so that arrows in the boxes became highlighted to provide feedback to the user about where the cursor was positioned. This reduced problems with linking so that subsequently users only experienced problems in the very early stages of using the software and they quickly became familiar with the technique. A further improvement was made in Expert Builder version 2 which is outlined in Section 10.9.2.

10.8.2.2 Cutting threads using the scissors

The mechanism of action of the scissors was considered to be poor at the outset but it was implemented in this way owing to time constraints. This was the feature that caused most frustration and in version 2 the scissors have been made to cut the thread at any point along its length.

10.8.2.3 Sizing boxes

The sizing tool caused few problems, the only minor problem being that some users tried to fit the tool exactly on to the box border whereas clicking anywhere in the box had the effect of making the cursor jump to the lower right hand corner allowing the user to size the box downwards and to the right. Nevertheless the sizing facility was limited to two directions so it was improved in version 2.

10.8.2.4 Printing

The printing facilities were very limited, owing to the limited time for implementation, and did result in some frustration, which the investigator overcame to some extent, by providing printouts of screens. The importance of printing facilities was emphasised by many users so version 2 provides a full range of printing facilities.

10.8.2.5 Facilities for restructuring the diagram

Facilities for restructuring the diagram were limited to moving individual boxes, owing to the limited time for implementation. During the classroom study some pupils were observed spending considerable time laying out their diagrams. It became clear that better facilities for restructuring were important so these were implemented in Expert Builder 2.

10.8.2.6 Nature of the links

The design decision to show the links as simple threads rather than arrows was to discourage users from thinking of the structure as a flow diagram but there were some users who argued forcibly for the use of arrows to show implication. Others felt that the arrows should point down the screen to show the direction of inference. This dilemma could only be resolved by further empirical work following changes to the software that are outlined in Section 10.9.2.

10.8.2.7 Display of the reasoning used

Some expert system shells including Adex Advisor, discussed in Chapter 2, provided a textual list of the rules that had been used to prove a conclusion. This was omitted from the Expert Builder because it was believed that the visual trace would be adequate and that the textual trace would simply be confusing. A small number of users who were aware of the trace in Adex Advisor felt that it was useful and should be provided in Expert Builder. Its usefulness was confirmed by a classroom activity based on the model shown in Figure 10.1. The textual trace of this type of model which involves a long chain of reasoning helped pupils to check each of the links.

10.8.2.8 Screen space

It was very obvious that the size of the screen was a limitation when constructing the diagram. During the classroom study most users were using screens of relatively low resolution (640 * 250 pixels) so only very small models could be shown in full on the screen at once. There was no complete solution to this problem given the existing technology; a much larger screen e.g. blackboard-sized would be desirable. Use of higher resolution screens would alleviate this problem to some extent as well as some of the improvements in making use of the long view, discussed in Section 10.9.

10.8.3 Limitations to the evaluation

The classroom evaluation study was obviously limited by time but also by the amount of access that pupils had to computers. This was typical of most classroom situations and it was felt to be important to carry out the evaluation in a normal classroom situation in order to determine whether the software was suitable for immediate use given current limited facilities in schools. The evaluation did not provide opportunities to explore the full potential of qualitative modelling that would be possible with enhanced resources or longer term use. The detailed study was limited to the primary age range. During this research some reports of the use of Expert Builder in secondary schools and for advanced level courses were received, which suggested that this style of modelling was appropriate at this level, but no detailed investigations were conducted.

10.9 Extensions

10.9.1 Extensions to the evaluation of Expert Builder

There are several ways in which this evaluation could be extended by further relatively limited studies that are discussed here.

An interesting further empirical investigation would be to take a small group of volunteer experienced computer users in the primary age range and to give them good access to the software over an extended period of several months in order to see what they might achieve and what modelling skills they could develop. The group would need to be given initial instruction in using the software probably by being shown how to build some simple models and then extra tutorial help on request.

A useful focus of this investigation would be to examine the development of modelling skills and abilities as specified by the list of goals in Chapter 9. This could be done using think-aloud protocols or interviewing pupils about their modelling at different stages in their work. One aim of such an investigation could be to explore pupils' recognition of analogous structures in models and their selection of structures.

An in-depth investigation of older pupils using Expert Builder would also be useful. One approach would be to conduct an investigation with secondary school pupils working on a particular subject, for example 13-14 year-olds studying science and to examine in detail what they have learnt from using Expert Builder for a modelling activity. This might be able to be done as a comparative study where one group was using Expert Builder to learn about a particular topic and another was using a different method. This comparative approach may require a more extensive investigation, as discussed in Section 10.10, because in order to enable a fair comparison the pupils would need to have developed some familiarity with modelling in this environment otherwise much of their time, during a relatively short piece of work on a topic, would probably be spent in becoming familiar with the software. A comparative study that was intended to reveal any enhanced learning using one learning approach over another would be subject to the constraints and problems discussed in Section 10.3.6 and would therefore need to be a fairly extensive study.

10.9.2 Extensions to the software - Expert Builder 2

In the light of findings from this research Expert Builder was improved and fully tested before being released and published as Expert Builder version 2 (Webb et al., 1993). Expert Builder version 2 was developed to run under Microsoft Windows 3 and incorporated the following improvements over the prototype version.

- When using the bobbin tool, instead of highlighting arrows a half box becomes highlighted when the bobbin is over it.
- The scissors cut the thread directly so that as well as being more intuitive in their use they provide immediate feedback to the user about the effect of her/his action.
- The more standard method of sizing from all corners and sides which allows greater flexibility in laying out boxes.
- Printing of the main diagram, the long view, clauses, rules and explanations is provided.

- It is possible to move and to cut and paste chunks of the diagram in the main view or long view.
- The tools are displayed on a tool bar beneath the menu bar which is more consistent with other Windows 3 products and is less obtrusive on screen space.
- Connections between boxes can be customised in one of three ways; simple threads as in the original version, upward pointing arrows or downward pointing arrows.
- A standard Windows 3 help facility is provided.
- A textual list of the rules that have been used to prove a conclusion is provided.
- Clauses can be edited by clicking on them in the long view. This facilitates editing and viewing of larger models and helps to alleviate the problem of limited screen space.
- The package incorporates precise error messages and highlighting of the error on screen.

10.10 Further work

10.10.1 Longer term evaluation

A longer term evaluation could enable the identification of specific learning outcomes that might be affected by computer based modelling in particular contexts and attempts could be made to measure these effects. Also in the longer term it would be useful to categorise the types of models that pupils produce and to investigate the extent of use across different subject areas. Activities could be compared in terms of their knowledge types and instructional environments using Kyllenon and Shute's technique, discussed in Chapter 9 (Section 9.3).

10.10.2 Variables

The design of the rule storage and inference mechanism of Expert Builder had allowed for the future incorporation of global variables. The future challenge would be to design a user interface that would maintain ease of use and enable users to build models incorporating variables. Some of the modelling tasks tackled during this study would have been facilitated by the provision of variables. Questionnaire returns from more experienced computer users requested such provision. In particular the use of tables that could be accessed by the expert system would extend modelling facilities.

10.10.3 Support for arithmetical operations

Expert Builder was designed as a qualitative tool but there are some models that are predominantly qualitative but still contain some numbers. This aspect is also considered in the Section 10.10.6 where the possibilities of integrating qualitative and quantitative facilities are examined. However, in addition to full integration of qualitative and quantitative facilities a more limited provision of some numerical operations was identified. In some models users wanted to incorporate rules such as "*the site is suitable for a settlement if water is less than 100 metres away*". In such cases it would be useful if end users could input the distance to water and the system could perform an arithmetical operation to check the rule. This more limited facility could be provided with only minor alterations to the package.

10.10.4 Exploring other user interfaces

The diagrammatic representation of the rule structure was designed to provide maximum flexibility while being easy to use and understand. The reasons for detailed design decisions were discussed in Chapter 5. Several of the decisions about the diagram were made after consultation with teachers having shown them simple mock-ups but it would have been better if it had been possible for teachers and pupils to work with functional prototypes of rule diagrams. This would not have been feasible within the timescale of this project but the implementation of the inference engine in Expert Builder was separate from the user interface so it would be possible to implement several different user interfaces. A further investigation would be to use different arrangements of the diagram, particularly one arranged the opposite way up and one arranged horizontally across the screen to determine which design was easiest for most people to use.

Another interesting study would be to compare the use of an environment in which rules are expressed purely in textual form with the use of a diagrammatic interface. Some evidence of the limitations of a textual interface were discussed in Chapter 4 but no comparative study has been done.

10.10.5 Exploring other qualitative modelling metaphors

In this research it was necessary to select one particular metaphor, rather than experimenting with several different ones, owing to time constraints. The reasons for choosing the rule-based metaphor, which were discussed in Chapter 4, included theoretical considerations and some evidence from empirical studies but the latter was quite limited. An interesting further study would be to compare the use of several different metaphors e.g. frames, decision trees.

10.10.6 Integrating qualitative and quantitative modelling

This was a longer term aim of the Modus Project to enable modellers to use both qualitative and quantitative techniques within the same model. The incorporation of variables would allow for the integration of these two styles of modelling. A variable could be accessed by both the qualitative and quantitative modelling processes. The design challenge would be to enable the use of a wider range of facilities while maintaining a simple to use system and adhering to the principle of naive realism. It was clear during this research that most educational users had very limited experience of modelling and it was unlikely that most would be able to make use of a more sophisticated facility within the near future. However there may be opportunities, even for younger users, to move on from developing simple qualitative models to exploring some quantitative aspects, e.g. the model on choosing a holiday included some consideration of the cost and how much the person could afford so one extension might be for the pupils to model how much a person could afford depending on how much they could save per week, etc. Obviously this could be done separately on a spreadsheet but it would be preferable if it could be built into the same model so that when it is run the user is questioned about her/his weekly savings and when they were hoping to go on holiday etc. and the model could carry out some calculations as well as using reasoning.

10.11 Final comment

The goal of this research was to find ways of using computers to enable learners to express and explore their ideas and understanding by building qualitative models which they could run and evaluate. The modelling environment, which has been developed in this project, has enabled this to be possible for pupils from nine years old upwards. Just as Papert (1984) stated with reference to Logo:

> *"fluency in programming provides an opportunity for teachers to teach in new ways and for students to learn in new ways."*

developing modelling ability using a qualitative modelling environment could open up more learning opportunities. The final comment is left for one of the pupils, Susan, who was 11 years old:

> *"By building it (the model) I had to research and I suppose I was doing extra research that I wouldn't normally have done before. It's making me find out more that I wouldn't normally do"*

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Appendix 1

Membership number

Expert Builder Questionnaire

Your establishment is now a member of the Modus Club and we hope that you will want to contribute to the evaluation of Expert Builder and the design of Modus. Please fill in this questionnaire when you have had time to develop some initial reactions to Expert Builder and have read the newsletters. There is no need to have used Expert Builder in the classroom at this stage as we shall be asking for your views again in a few weeks time. Please note that we shall put this information into a database for easy analysis. If you have any comments to make about aspects which are not covered on this questionnaire, please send them to us. We are interested in any comments.

Please return the completed questionnaire to the Advisory Unit in the envelope provided. An additional sheet is provided for you to report on any classroom work which you do with Expert Builder. We are trying to build up a collection of examples of classroom work.

Returning this questionnaire will ensure that you are kept informed about Modus and you are supplied with example models and trial materials as they become available.

1. **Your details:**

Surname: ____________________

Forename: ____________________

Title: (delete as appropriate) Mr, Mrs, Ms, Dr.

Position in institution: ____________________ Telephone number:

EMAIL number: ____________________ Fax number: ________

2. **Where you work.**

Institution Name: ____________________

Type of Institution (tick as appropriate):

Junior School	Middle School
Secondary School	6th Form College
Further Education	Higher Education

Other (please specify) ____________________

Age range of students: ____________________

Subjects taught: ____________________

3. **Your ideas about modelling:**

Do you use any software for modelling at present? YES/NO

If YES,
please give names of software ______________________________

What ideas do you have about the kind of computer based modelling facilities you would like?

____

____

____

In what topics would it be worthwhile doing some computer based modelling?

____

____

____

How do you think children might benefit from doing computer based modelling?______________________________

____

____

4. **How will you use Expert Builder?**

Had you used any expert system shells before Expert Builder? YES / NO.

If yes please specify ______________________________

____

Do you intend to use Expert Builder with your students? YES / NO

If NO, please give your reasons ______________________________

____

If YES, which age range of students do you expect to use Expert Builder? ________

What topics do you expect to work on? ______________________________

____

____

Any further comments on your plans for using Expert Builder?

____

5. **Expert Builder Diagram or Expert Builder Text?**

Which interface did you prefer to use? Expert Builder Diagram / Expert Builder Text

Did you find the Expert Builder Diagram generally easy to use? YES / NO

Any comments on the diagrammatic technique for building rules?

____

____

____

Did you find the tools e.g. scissors, cotton reel etc. easy to use? YES / NO

Any comments on the tools? ______________________________

____

____

Please grade the following features of Expert Builder by ringing a number from 1 to 4 where:

4 = very useful 3 = useful 2 = unnecessary 1 = unsuitable

The ability to represent rules diagrammatically	1	2	3	4
The ability to see a trace of the reasoning on the diagram	1	2	3	4
The ability to provide your own textual explanation of clauses	1	2	3	4
The ability to use pictures to explain clauses	1	2	3	4
The Why? facility in Expert Builder Text to trace the reasoning	1	2	3	4
The Title Page facility	1	2	3	4

Are there any other facilities of Expert Builder which you particularly like?

____

____

____

Are there any other facilities of Expert Builder which you particularly don't like?

____

____

____

Are there any facilities missing which you would like to be included?

____

____

6. **Expert Builder in use:**

Have you written an expert system in Expert Builder? YES/NO

If yes, on which topics? ______________________________

How many rules (approximately)? ______________________________

Have you used Expert Builder with any students? YES/NO

If YES, in which curriculum areas? ______________________________

(Please fill in the additional sheet about students' work if applicable.)

Any comments on classroom use? ______________________________

____

____

____

____

Is Expert Builder being used by other teachers in your institution? YES / NO

If YES, which subject areas?______________________________

Do you think Expert Builder would be suitable for use in other subject areas?
YES / NO

If YES which subject areas? ______________________________

____

Do you intend to introduce other teachers in your institution to Expert Builder?
YES / NO

Have you any comments about the opportunities / problems associated with introducing Expert Builder to other teachers?

____

____

____

7. **Expert Builder Guide:**

Did you use the tutorial chapters to help you get started? YES / NO

Have you used the reference section? YES / NO

Have you any comments on the style, organisation or contents of the guide?________

____

____

Appendix 2 Summary of returns of Expert Builder questionnaires

January 1991

Introduction

Out of a total of approximately 140 members, 23 have returned questionnaires and of these 6 have provided examples of systems they have built.

School Details

Type of Institution

Junior School	2
Secondary School	8
6th Form College	1
Further Education	1
Higher Education	4
Teacher education	4
Advisory centre	3

Subjects taught

IT	19
Maths	1
Geography	1
business studies	1
all	2

Ideas about modelling:

Do you use any software for modelling at present?

YES	15
NO	8

Names of software used

(numbers in brackets indicate the number of users who mentioned the software)

spreadsheets (4)
FGP (graph plotter)
Excel (6)
CMS (2)
STELLA (2)
KEE
Claris (CAD)
DMS (2)
IQON
Adex
Multiplan (2)
Logistix (2)
Quest
LIMITS
BASIC
FORTRAN
Lotus123

BCSSP (differential equations)
Derive (analysis)
Prolog (2)
Lisp
Logo (2)
Knowpad (2)
Numerator
Arrow

What ideas do you have about the kind of computer based modelling facilities you would like?

(Numbers in brackets indicate that the comment was made by more than one respondent)

Branching tree structured systems.
Graphic interface is essential (3).
Number crunching.
Flow chart style linked to graphical output (Numerator+).
Easier version of STELLA type with on-line support.
Display of spatial models.
Mathematical modelling, statistical distributions.
Graphics based front ends.
Models to explain how business systems work.
High entry price for modelling software at present both in money and time.
Forward chaining, easy to use, powerful, fast.
Qualitative modelling tool (of the -10, -1, +1, +10 in X and dX type).
How about a simple sorted logic browser or a classification tool (to explore type networks, plant Classification, default reasoning etc.).
Constraint based, stochastic, knowledge based.
Must be ultra easy to use, instruction minimal, good clear examples.
As outlined in Modus newsletter 1.

In what topics would it be worthwhile doing some computer based modelling?

Environmental systems.
Economics, accounts.
Biology, maths, vocational selection, home economics.
Wage slip, cash flow, balance sheet, petty cash, bank account, postal systems.
Across curriculum.
Angle theorems - decision tree based using definitions/concepts.
Business studies, anthropology, (organisations and people), engineering (modelling less certain decisions), land use planning.
Most junior school work lends itself.
Population dynamics, equilibrium reactions in science, weather systems.
Ecology.

How do you think children might benefit from doing computer based modelling?

Increased understanding and enthusiasm through ownership of the completed model.

How will you use Expert Builder?

Had you used any expert system shells before Expert Builder?

YES	15
NO	8

Expert system shells used

(Numbers in brackets indicate that the shell was used by more than one respondent)

ESTA (turbo prolog)
First Expert
Crystal (3)
Xi (3)
Xi plus
Master Builder
Mahogany
Prolog (3)
Flex (3)
Adex (5)
Apes (5)
Esie
Knowpad (3)
Refine
Simple (Prolog)
Mitsi
KEE

Do you intend to use Expert Builder with your students?

YES	18
NO	5

Reasons for not using Expert Builder with students

Hopes to but headmaster has changed the general studies course where he intended to try it.
Too time consuming.
I train staff not students.

Age range of students to use Expert Builder?

9-11	2
11-14	3
14-16	3
16-18	9
adult	3

What topics do you expect to work on?

(Numbers in brackets indicate that the comment was made by more than one respondent)

Battle of Hastings.
Foreign language learning, structuring knowledge bases.
Environmental systems.
Classification of animals/plants, general problem solving.
Examples from maths and economics.
Introduction to expert systems, students get lost in Crystal and graphical front end ideal for early phases.
As example of expert system shell.
choosing statistical tests.
Varied.
Cross curricular.
Angle theorems, properties of quadrilaterals, trig, Pythagoras.
Sport, health and physical ed..

Science, environmental studies.
Many.
Examples to show how expert systems work. (2)
Communications.
Economics, accounting.

Any further comments on your plans for using Expert Builder?

Selecting strategy when solving mathematical problems e.g. determining the extreme values of a function.
Intends demonstrating EB in non-computer literate areas. may use EB in a student advisory role in-house and for schools.
May introduce to younger students later
Summer vacation project.
Evaluation and introduction for county.
Intend to introduce gradually to small groups. work will be experimental and time consuming, other teachers may use it for other purposes.
Groups of 2/3 building own model.

Expert Builder Diagram or Expert Builder Text?

Which interface did you prefer to use?

Expert Builder Diagram	17
Expert Builder Text	1

Did you find the Expert Builder Diagram generally easy to use?

YES	16
NO	3

Any comments on the diagrammatic technique for building rules?

Confused about the difference between a question and advice.
Preferred for future rather than text based system.
More on help facility needed.
Very clear.
Most children wanted to start from the bottom up.
Much easier than EBT. Many dialogue boxes in EBT are confusing.
Bit sensitive for those not used to mouse.
Good but diagram gets too big very quickly. a reduce option would be useful, somewhere between long and full view. can get spaghetti-like if expert system is at all complicated.
Very good use of Windows, very easy to use.
Can become spaghetti like.
Default processing from left is extra logical feature which students make use of - should be removed.
Conceptual problems for some.
Some uncertainties in making connections.
I like it.
An arrow from condition to consequence would make it clearer.
Excellent idea

Did you find the tools e.g. scissors, cotton reel etc. easy to use?

YES	17
NO	3 (One said "but children did")

Any comments on the tools?

Very easy.

Exact location of hot spot was not always clear.
Scissors didn't always work.
Scissors difficult.
Difficult to attach thread to AND/OR boxes.
Scissors dreadful.
Scissors expected to cut thread.
Scissors too delicate.
Quite awkward to use.
Sizing tool difficult - cant let go of the mouse button and pick it up again -have to drag.
Icons difficult to see - need idiot card.
Scissors and cotton reel take a bit of getting used to but can't think of a better method.
Cotton reel sometimes fiddly too many tools, too confusing to join boxes, cannot easily tell if AND etc. is actually joined.

Grade features of Expert Builder by ringing a number from 1 to 4 where:

The ability to represent rules diagrammatically
very useful 13
useful 7
unnecessary 0
unsuitable 1

The ability to see a trace of the reasoning on the diagram
very useful 14
useful 6
unnecessary 0
unsuitable 1

The ability to provide your own textual explanation of clauses
very useful 6
useful 12
unnecessary 3
unsuitable 0

The ability to use pictures to explain clauses
very useful 9
useful 5
unnecessary 5
unsuitable 0

The Why? facility in Expert Builder Text to trace the reasoning
very useful 6
useful 12
unnecessary 3
unsuitable 0

The Title Page facility
very useful 2
useful 8
unnecessary 10
unsuitable 1

Are there any other facilities of Expert Builder which you particularly like?

(Numbers in brackets indicate that the comment was made by more than one respondent)

Ability to move window in long view (4)
Longview
Hand for moving
The HCI and the fact that it uses MS Windows
EBT rule editor
Moving boxes, colour trace

Are there any other facilities of Expert Builder which you particularly don't like?

Scroll bars are slow
Can't use question mark for moving in Long view. printing Longview - boxes are too small.
Tool box disappears when you Use Expert.
On network moving diagram is painfully slow.
Slow scrolling.
Windows too slow (N.B. using on 1MB dual disc).
Non VGA compatibility - models in CGA boxes too small in VGA, cotton reel clumsy.
Click or double click.
Printout of long view is very small, not truly compatible with other windows applications - would like to be able to cut and paste the diagram, screen updating slow.

Are there any facilities missing which you would like to be included?

(Numbers in brackets indicate that the comment was made by more than one respondent)

Variable font size.
Spatial display - maps.
Felt need for IF statement.
More helpful error messages. N.B. bug problem here - Unable to talk to expert.
When will ARC version be out?
Ability to handle numeric / algebraic expressions and calculations.
Copying parts of diagram, to save colour configuration to local disk rather than server, variables, versioning.
Print of full diagram (3).
Facility to ask system - why do ask that question,
Variables.

Expert Builder in use:

Have you written an expert system in Expert Builder?

YES	15
NO	6

If yes, on which topics?

Advice on solving a particular problem.
Accounts.
Postal system.

Help guide.
Student advice on course choice.
Buying a computer.
Geography, IT.
Munich Agreement.
Quads, triangle calculates (trig).
Holiday choice.
Choosing a suitable expert system application.
Communication.
Purpose of computers.

How many rules (approximately)?

6,40,4,25,30,25,10,8,14,30,6,20,10

Have you used Expert Builder with any students?

YES	13
NO	6

If YES, in which curriculum areas?

(Numbers in brackets indicate that the comment was made by more than one respondent)

Geography
Accounts
Office studies
IT (4)
Computing
Varied
Science
History,
Environmental studies
Cross curricular
Technology

Summary of students work

Double entry book-keeping.
14-15 mixed ability - postal system.
10 lessons on network. Demonstration of expert systems. Set tasks to experiment with prebuilt systems then build own. Crib sheets p75/76 and 43/44 of guide. Examples sent - airline prep, bike journey, D&T key stages.
Educational computing students.
Used with couple of 14 year olds.
6 hours, workshop. canoe training schedule for competition season. demo then brief work with students building own. Not completed.
Senlac hill, conservation management as class exercise.
Half hour demonstration followed by 1 hour workshop to build model on any topic. modest results.
Which method of communication to chose.
Construction and evaluation of an expert system - comparing Adex, EB and LPA FLEX - system on how to grade a jibbock (worksheet sent).

Comments on classroom use

No more than 2 to a machine
Worthwhile for getting students to think logically about a task. Best to get students to plan on paper first.
Lack of hardware - few machines with windows or mice.

First expert system shell seen which could realistically be used in a cross curricular context. All others far to difficult to use.
Children found it fun and had little difficulty with tools. Metaphor hard.
Some conceptual problems. Technically OK.
Slow to start but students learnt v quickly. Good learning for students, vocabulary extension and exact use of words.
Students found it very interesting and enjoyed the intellectual challenge. It is a splendid and entrancing bit of software with huge potential.
Easy to understand, not enough time.
Good class organisation essential.
Excellent program.

Is Expert Builder being used by other teachers in your institution?

YES	1
NO	12

If YES, which subject areas?

Humanities.

Do you think Expert Builder would be suitable for use in other subject areas?

YES	11
NO	0

If YES which subject areas?

(Numbers in brackets indicate that the comment was made by more than one respondent)

Most (3).
All.
Science (2).
History.
Computer science, business studies, civil engineering, chemical engineering, admin. language development

Do you intend to introduce other teachers in your institution to Expert Builder?

YES	8
NO	4

Have you any comments about the opportunities / problems associated with introducing Expert Builder to other teachers?

Teachers need to modify their approach to teaching, changing from a delivery style to an exploratory style.
Need an example for their subject area. Need to know system well before introducing.
Hardware problems.
Will be introducing EB to humanities teachers as part of a days course on IT in humanities June 1990.
Overall finish of product too crude to introduce to staff who lack confidence with software.
Lack of expertise and confidence with everyday computer usage. Expert systems need a lot of confidence.
No problems.
Previous experience may cause problems.
Need familiarity with Windows environment.

Expert Builder Guide:

Did you use the tutorial chapters to help you get started?

YES	18
NO	3

Have you used the reference section?

YES	17
NO	3

Have you any comments on the style, organisation or contents of the guide?

(Numbers in brackets indicate that the comment was made by more than one respondent)

Good (2).
Good, some inconsistencies.
Clear, concise and easy to follow. division between tutorial and reference useful.
OK (2).
Good for adults.
Pupil guide needed (2).
Very clear and well laid out.
Very good.
Generally very clear and helpful.
Looks fine but the system is dead easy to use anyway.
Generally good.

Appendix 3 Student Interview

To be conducted with students in pairs after they have built a model in Expert Builder. Questions will generally alternate between the 2 students although if no answer is forth coming from one the other may answer.

1 You have helped to build a system about --- (habitats and conservation). What is the purpose of the system?

2 If I wanted to use your system, what would I need to do? (If necessary, prompt further - What do I need to know?, How do I use it?, What sort of answers would I need to give to the system?, What sort of answers will it give me?)

3 Do you think systems like this are useful? Why?

4 How do you think the program works? When you chose the question mark tool, boxes colour in on the screen. Can you explain what is happening?

5 Do you think that building this system helped YOU to learn anything? Explain

6 What do you think of the program? (Do you like using it?, Why?, Did you find it difficult?, Anything you didn't like?)

Appendix 4 Expert Builder - Test of Competency

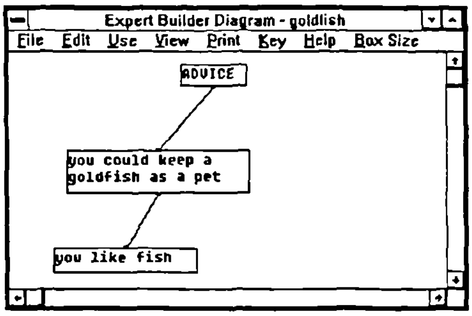
This test will be given to students after they have been using Expert Builder for a period of time. The first part of the test, Exercises 1 and 2 will be given to individual students and is expected to take 20 minutes. If students can't answer a question the answer will be explained to them. Exercise 3 will be done in pairs.

Procedure

The student will be asked questions orally and will work at a computer screen

Exercise 1

The student is presented with a simple model which advises on whether someone could keep a goldfish as a pet (goldfish.ebd).



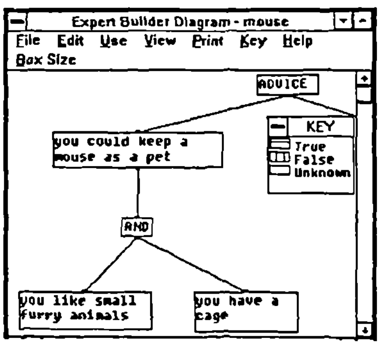
1 Get the question mark tool		Selection on first click (mouse manipulation)
2 Tell me what will happen if you click on advice		ask if you like fish (understanding of inference)
3 Click on advice		Accurate click (mouse manipulation)
4 If you say yes what will happen?		say you could have a goldfish. (understanding of inference)

Let them click on yes, then OK
Investigator drags out window to show box "you like mice"
Add to the system so that it tells you could keep mice if you say you like mice

5		box tool (tool use)
6		create box (tool use)
7		you could keep mice
8		advice tool (tool use)
9		advice box (tool use)
10		box-box link made (linking)
11		advice - box link made (linking)
problem		number of unsuccessful attempts at link (linking)

Exercise 2

Show them the model which advises whether you could keep a mouse as a pet(mouse.ebd).

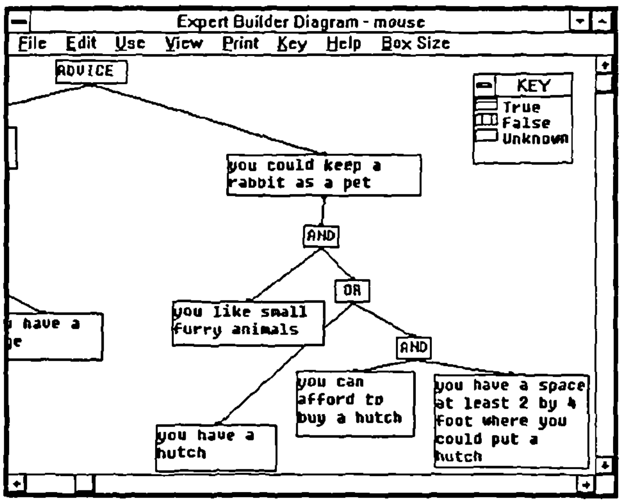


12 Use the tick to tick the boxes so that when you click on Advice with the question mark it will say you could keep a mouse as a pet?
Change AND to OR

Tick both. (understanding of AND)

explanation (content / logic)
Tick one only & explain

Investigator moves the view on mouse.ebd so that they can see part of model which advises on whether someone could keep a rabbit.

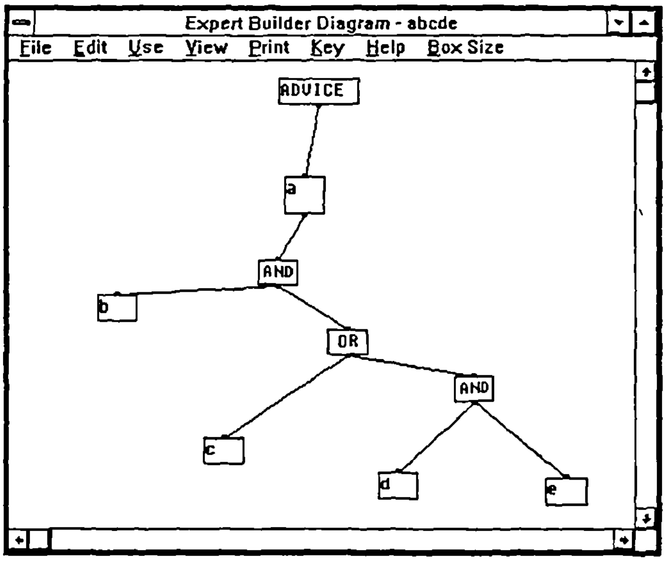


13 Use the tick to tick the boxes so that when you click on advice with the question mark it will say you could keep a rabbit as a pet?
Why have you ticked those boxes

Tick both

explanation content or logic

Investigator loads the file ABCD.ebd which has the same logical structure but no text.

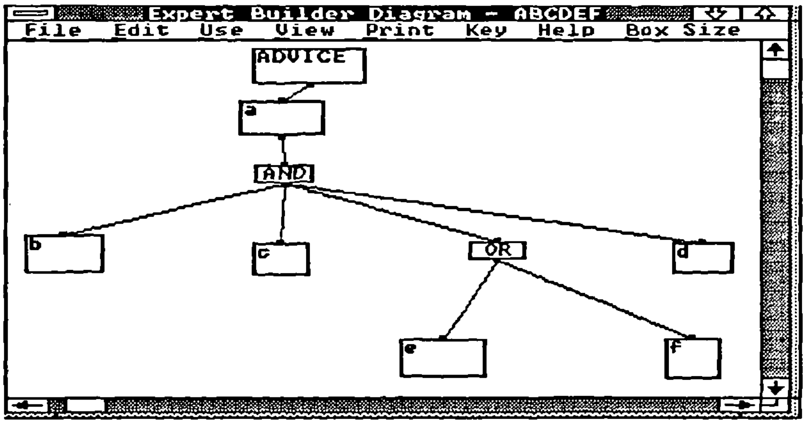


14 Use the tick to tick the boxes so that when you click on advice with the question mark it will colour a red for true (point to a)
Why have you ticked those boxes

Tick both b & c

Analyse explanation

Investigator loads the file ABCDEF.ebd

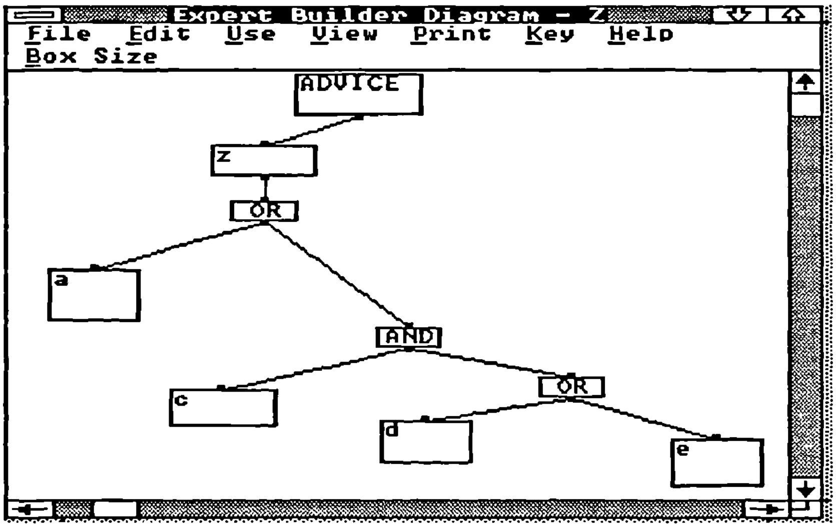


15 Use the tick to tick the boxes so that when you click on advice with the question mark it will colour a red for true (point to a)
Why have you ticked those boxes

Tick b,c,d and e or f

Analyse explanation

Investigator loads the file Z.ebd



16 Use the tick to tick the boxes so that when you click on advice with the question mark it will colour z red for true (point to z)
Why have you ticked those boxes

Tick a

Analyse explanation

Exercise 3

Start on a new model to see whether they can make use of the metaphor to fit a new situation without any clues provided. Students will work in pairs. They will be presented with a card, outlining the scenario. One student will role play the expert and the other the person being given advice. The "expert" will be asked to give verabl advice first of all and the other will ask questions. When they go on to build the computer model they will both work together.
Scenario. In the village where Jane lives there are 2 shops - a bakers and a post office. They are both within walking distance of Jane's house. About 5 miles away to the west, there is a large supermarket which sells a wide range of foods. In the town, which is 10 miles awayto the east, there many shops selling most of the things which she might want. You are going to write a system which will advise Jane where to go to buy the things she needs. Whenever Jane needs something from a shop your system should be able to advise her where to go. Students are presented with this on a card to remind them.

18 Describe in words what you would advise Jane to do		Record and make notes on software interaction.
19 Now write a system which will advise Jane what to do		Record and make notes on software interaction.

The students will be allowed to work without prompting unless they are judged to be completely stuck. They will then be given help in using the software and this will be recorded. If students are short of ideas, the student role playing Jane will be prompted to think about what she might need to know. If he/she is still unable to ask relevant questions she/he will be given questions on cards such as:

Where should I go to buy some bread?

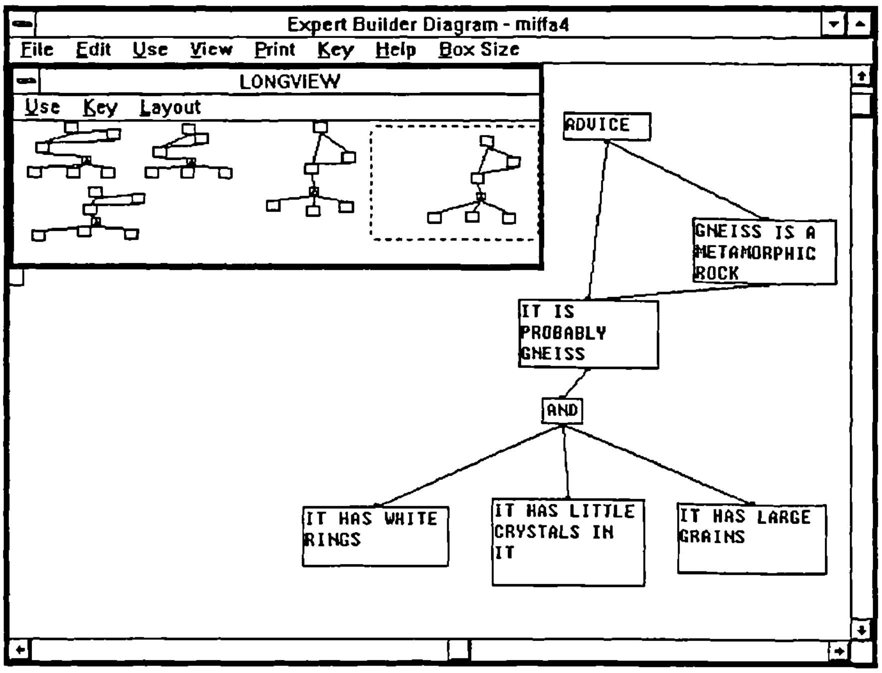
Where should I go to buy some stamps?

I need to buy some food for next week and also I need a table Where should I go?

I need some bread, milk, eggs and fruit, where should I go?

Appendix 5 Model for identifying rocks

One of the models for identifying rocks built by pupils in school C



ADVICE
CHALK IS A SEDIMENTARY ROCK
[IT IS FORMED BY DEPOSITED REMAINS OF ANIMALS. SEDIMENTARY ROCKS ALWAYS HAVE STRATA. SEDIMENTARY ROCKS WILL ALSO WEATHER, BE TRANSPORTED,BE REDEPOSITED AND FORM SEDIMENTARY ROCKS AGAIN. SEDIMENTRY COMES FROM THE LATIN WORD SEDEO, IT MEANS TO SIT DOWN OR SETTLE DOWN. ALL SEDIMENTRY ROCKS HAVE LAYERS. THESE LAYERS ARE CALLED STRATA OR BEDS. THE PARTICLES MAY HAVE BEEN MADE BY THE ACTION OF WATER OR WEATHER ON ROCKS. MILLIONS OF YEARS AGO TINY SEA CREATURES DIED AND SANK TO THE BOTTOM WHERE THERE BONES BUILT UP. AS TIME PASSED THE LAYERS STUCK TO FORM SEDIMENTARY ROCKS.]
GNEISS IS A METAMORPHIC ROCK
[THERE ARE TWO WAYS IN WHICH METAMORPHIC ROCKS ARE MADE - BY CONTACT OR BY REGIONAL METAMORPHISM. CONTACT METAMORPHISM OCCURS WHEN MOLTEN MAGMA FORCES ITS WAY INTO PRE-EXISTING ROCK. A LAYER OF THIS ROCK UNDERGOES METAMORPHIC CHANGE. IT CAN BE FROM A FEW METRES TO OVER A KILOMETRE THICK. REGIONAL METAMORPHISM, AS THE NAME IMPLIES, TAKES PLACE OVER A MUCH WIDER AREA. IT OCCURS DURING IN PERIODS OF MOUNTAIN - BUILDING AS THE ROCKS ARE COMPRESSED AND DEFORMED.]
GRANITE IS A IGNEOUS ROCK
IT HAS GOT LARGE GRAINS
IT HAS LARGE GRAINS
IT HAS LAYERS
IT HAS LINES ON SURFACE

IT HAS LITTLE CRYSTALS IN IT
IT HAS LITTLE CRYSTALS IN IT
IT HAS SMALL CRYSTALS IN IT
IT HAS SMALL GRAINS
IT HAS SMALL SHELLS IN IT
IT HAS VERY SMALL GRAINS
IT HAS WHITE RINGS
IT IS MOSTLY WHITE
IT IS MOSTLY WHITE WITH GREY FREKLES
IT IS PROBABLY CHALK

[CHALK CAN BE FOUND IN CLIFFS. IT CAN BE USED ON A BLACKBOARD ,IT HAS MANY OTHER USES. IT IS SOMETIMES SHAPED IN STICKS.THERE ARE CHALK CLIFFS ALONG THE SOUTH COAST AND IN THE CHILTERN HILLS NEAR WYCOMBE.]

IT IS PROBABLY GNEISS
IT IS PROBABLY GRANITE
IT IS PROBABLY LIMESTONE

LIMESTONE IS FORMED FROM CORAL. CORAL IS THE HARD SKELETON OF TINY ANIMALS THAT LIVE IN TROPICAL SEAS.MARBLE IS FORMED FROM LIMESTONE. WHEN A STREAM RUNS OVER LIMESTONE ROCK, IT DESSOLVES A LITTLE OF THE ROCK. LIMESTONE CAVES ARE ONE OF THE GREAT WONDERS OF NATURE.]

IT IS PROBABLY MARBLE

[MARBLE IS HARD ROCK. IT CAN BE USED FOR BUILDING STATUES, IT IS ALSO USED FOR FLOORS. IT IS METAMORPHIC AND IS CHANGED FROM LIMESTONE.]

IT IS PROBABLY OLD RED SANDSTONE
IT IS REDDISH IN COLOUR
IT IS ROUGH
IT IS WHITE
LIMESTONE IS A SEDIMENTARY ROCK

[IT IS FORMED BY DEPOSITED REMAINS OF ANIMALS. SEDIMENTARY ROCKS ALWAYS HAVE STRATA. SEDIMENTARY ROCKS WILL ALSO WEATHER, BE TRANSPORTED,BE REDEPOSITED AND FORM SEDIMENTARY ROCKS AGAIN. SEDIMENTRY COMES FROM THE LATIN WORD SEDEO, IT MEANS TO SIT DOWN OR SETTLE DOWN. ALL SEDIMENTRY ROCKS HAVE LAYERS. THESE LAYERS ARE CALLED STRATA OR BEDS. THE PARTICLES MAY HAVE BEEN MADE BY THE ACTION OF WATER OR WEATHER ON ROCKS. MILLIONS OF YEARS AGO TINY SEA CREATURES DIED AND SANK TO THE BOTTOM WHERE THERE BONES BUILT UP. AS TIME PASSED THE LAYERS STUCK TO FORM SEDIMENTARY ROCKS.]

MARBLE IS A METAMORPHIC ROCK

[THERE ARE TWO WAYS IN WHICH METAMORPHIC ROCKS ARE MADE - BY CONTACT OR BY REGIONAL METAMORPHISM. CONTACT METAMORPHISM OCCURS WHEN MOLTEN MAGMA FORCES ITS WAY INTO PRE-EXISTING ROCK. A LAYER OF THIS ROCK UNDERGOES METAMORPHIC CHANGE. IT CAN BE FROM A FEW METRES TO OVER A KILOMETRE THICK. REGIONAL METAMORPHISM, AS THE NAME IMPLIES, TAKES PLACE OVER A MUCH WIDER AREA. IT OCCURS DURING IN PERIODS OF MOUNTAIN - BUILDING AS THE ROCKS ARE COMPRESSED AND DEFORMED.]

OLD RED SAND STONE IS A SEDIMENTARY ROCK

[IT IS FORMED BY DEPOSITED REMAINS OF ANIMALS. SEDIMENTARY ROCKS ALWAYS HAVE STRATA. SEDIMENTARY ROCKS WILL ALSO WEATHER, BE TRANSPORTED,BE REDEPOSITED AND FORM SEDIMENTARY ROCKS AGAIN. SEDIMENTRY COMES FROM THE LATIN WORD SEDEO, IT MEANS TO SIT DOWN OR SETTLE DOWN. ALL SEDIMENTRY ROCKS HAVE LAYERS. THESE LAYERS ARE CALLED STRATA OR BEDS. THE PARTICLES MAY HAVE BEEN MADE BY THE ACTION OF WATER OR WEATHER ON ROCKS. MILLIONS OF YEARS AGO TINY SEA CREATURES DIED AND SANK TO THE BOTTOM WHERE THERE BONES BUILT UP. AS TIME PASSED THE LAYERS STUCK TO FORM SEDIMENTARY ROCKS.]